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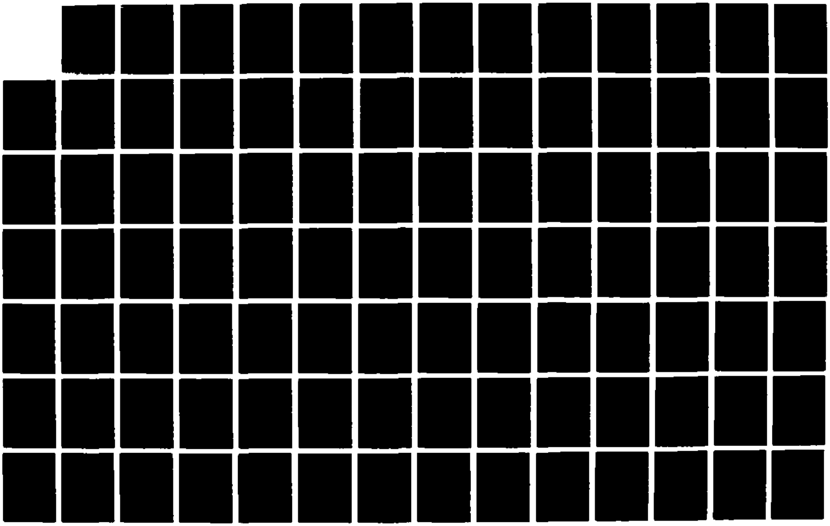

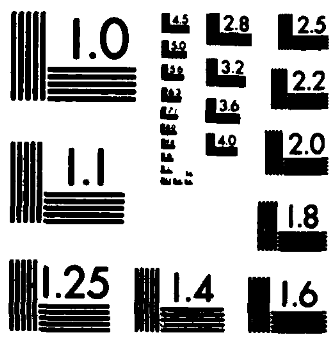

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The Pennsylvania State University

The Graduate School

Department of Civil Engineering

A Model for Scheduling and Analyzing

Construction Weather Delays

N00228-85-G-3278

A Report in

Civil Engineering

by

Frank Anthony Cantwell

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Engineering

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

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Chapter I

INTRODUCTION

Weather is one of the most difficult factors for contractors to evaluate in the preparation of construction plans. Because of this problem, some contractors either inadequately consider weather impacts or disregard them altogether. Consequently, they may fail to complete work within the time period allotted by their contracts. Adverse weather is considered by contractors, architects, and engineers to be the most prominent cause of lost time and delays on construction projects [1]. When weather conditions create safety hazards (eg. structural steelwork in icy conditions) or poor productivity (eg. earthwork in rainy conditions), contractors delay work until conditions improve.

Construction contracts usually require contractors to consider normal weather delays in the preparation of their schedules. Furthermore, these contracts allow time extensions when unusually severe weather impacts the scheduled construction. This implies that time extensions will not be granted for the impacts on construction caused by typical weather. What are 'normal' weather and 'unusually severe' weather? The inability of many contractors to answer these questions is often the root cause of their failure to consider potential weather impacts in their schedules. For an owner, the inability to answer these questions makes evaluation of weather-related time extension requests difficult.

It is difficult to include anticipated weather delays into a construction schedule for several reasons:

1. weather forecast accuracy affects short term plans.
2. the forecasting period affects the accuracy of the predicted weather.
3. weather conditions can vary significantly within a geographic region.
4. literature on scheduling techniques inadequately detail methods for including weather contingency.

Weather forecasts are not always accurate. Contractors have occasionally deferred scheduled concrete pours on the basis of predicted precipitation, only to find that the forecast was incorrect and the pour could have been made as originally planned. The forecast period affects consideration of weather effects on the schedule in that, as the period is extended, the accuracy of the forecast decreases. A five-day weather forecast is less accurate than a twenty-four hour forecast. Variability of weather conditions within geographic regions is also a major concern in scheduling weather contingency. The weather recorded by the National Weather Service or a private meteorological organization closest to a construction site may be vastly different than the weather conditions experienced at the site. Only in regions where adverse weather extremes for precipitation, temperature, relative humidity, and wind seldom occur can weather be ignored. Finally, contractors are ill-equipped

to estimate weather delays that will occur during the time allowed for contract completion. Scheduling handbooks provide caveats to contractors that weather delays must be considered in their schedules without providing guidance on how to interpret and incorporate climatological information.

This report presents a model enabling contractors to include normal weather delays into Critical Path Method (CPM) schedules through proper application of historical climatological data. Furthermore, the model enables an owner to assess weather-related time extension requests.

Background

The timely acquisition of new facilities or facility rehabilitation is essential to the needs of both public and private owners. For private owners, reliance might be placed on construction completion dates to project income from rentals, manufacturing, or other sources. For public owners, construction completion dates represent the culmination of planning and legislative processes to acquire facilities needed for services such as defense, law enforcement, and public transportation. Because delayed construction can severely impact on the needs of public and private owners, the time allowed for contract completion is a crucial aspect of construction contracts.

Contractors on construction contracts are required to complete construction no later than the completion date specified in their contract; however, circumstances that

include change orders, acts of God, unusual weather, and other causes beyond the control of the contractor, often prevent this. Delays may also occur when a contractor fails to plan or control adequately the construction process for a project, resulting in out-of-sequence activity performance and work space congestion. When delays beyond the control of the contractor occur, the contractor is permitted to request an extension of the contract completion date. Pertinent excerpts from the Federal Acquisition Regulations (FAR) cited in Federal construction contracts regarding time extensions are listed below:

> "...(b) The Contractor's right to proceed shall not be terminated nor the Contractor charged with damages under this clause, if-
> (1) The delays in completing the work arises from unforeseeable causes beyond the control and without the fault or negligence of the Contractor. Examples of such causes include (i) acts of God or of the public enemy, (ii) acts of the Government in either its sovereign or contractual capacity, (iii) acts of another Contractor in the performance of a contract with the Government, (iv) fires, (v) floods, (vi) epidemics, (vii) quarantine restrictions, (viii) strikes, (ix) freight embargoes, (x) unusually severe weather, or (xi) delays of subcontractors or suppliers at any tier arising from unforeseeable causes beyond the control and without the fault or negligence of both the Contractor and the subcontractors or suppliers..."[2].

Contractors are also required to submit detailed schedules showing their breakdown of construction operations and the time frames within which the operations will be performed. Schedules are vital to both the construction contractor and to the owner. For the contractor, the schedule provides a plan for attack of meeting his contractual obligations. For the owner, the schedule provides a benchmark

for monitoring the contractor's progress and it also provides assurance that the contract will be completed on time. Pertinent FAR clause excerpts regarding scheduling are listed below:

> (a) The Contractor shall within five days or another period of time determined by the Contracting Officer, prepare and submit to the Contracting Officer for approval three copies of a practicable schedule showing the order in which the Contractor proposes to perform the work, the dates on which the Contractor contemplates starting and completing the several salient features (including acquiring of materials, plant and equipment). The schedule shall be in the form of a progress chart of suitable scale to indicate appropriately the percentage of work scheduled for completion by any given date during the period. If the Contractor fails to submit a schedule within the time prescribed, the Contracting Officer may withhold approval of progress payments until the Contractor submits the required schedule [3].

When the contract requirements for scheduling and time extensions are read as a whole, it is clear that contractors will not be entitled to time extensions for normal weather delays, and therefore, normal delays must be incorporated into the construction schedules.

There are important legal considerations regarding schedules and time extensions. When contractors are entitled to a time extension for a verified weather-caused delay, the owner is obligated to provide an equitable adjustment to the contract completion time. Should the owner fail to fulfill this obligation, he or she will become legally liable for the constructive acceleration of the contractors' efforts, should the contractor strive to meet the current contract completion date.

This report describes a method for contractors to in-

corporate normal weather delays into their construction schedules. The report also describes a method for owners to evaluate time extension requests due to weather-related delays. Given the legal ramifications of a project schedule, this method could serve as an evidentiary tool in claims concerning weather-related time extensions. The method could also benefit both parties by providing better planning and reducing claims.

Problem Statement

Contractors for public and private construction contracts are required to complete their work within the time allowed and according to their construction schedules. In some instances, contractors plan to complete work earlier than the contract completion date. Contractors must include normal weather delays within their schedules. The contract will not allow time extensions for average weather encountered by the contractors during the course of construction. Literature on CPM scheduling frequently states that contractors should consider lost time due to weather [4,5,6,7,8,9]. Weather scheduling methods include:

1. Add a final activity to the network or schedule to account for the cumulative effect of weather delays.
2. Remove dates from the project calendar in a manner similar to the way holidays are excluded to allow for lost time due to weather. This, in effect,

shortens the available work calendar.

3. Use shortened work weeks during adverse weather periods.

4. Increase the durations of activities that are considered weather-sensitive.

None of these methods have been confirmed as entirely successful at factoring lost weather time into schedules. Each of these heuristic methods has its limitations. The final-activity approach does not link estimated lost time due to weather to weather-sensitive activities. It also makes weather-related time extension requests difficult to evaluate and justify while the job is in progress. Using shorter work weeks or removing calendar dates impacts on non-weather-sensitive activities. Increasing activity durations to account for weather is the most preferable approach, but it causes difficulty in evaluating planned versus actual productivity. Also, techniques for quantifying the duration increase are either complicated or arbitrary. Weather simulation models have not gained acceptance due to their complex, probabilistic nature. Calendar-Day algorithms apply weather factors that inadequately consider historical climatological data.

A straightforward methodology that enables contractor to identify when average weather delays will probably occur should be developed. The methodology could be adjusted to enable an owner to adequately evaluate time extension requests due to weather. In other words, the adjusted method

should allow the owner to identify the weather conditions that impacted the schedule. It should also quantify the difference between the weather conditions that caused the delay and historically average weather to determine the extent to which the contract should be extended.

Objectives

The primary objective of this study was to develop a method that would enable a contractor to effectively consider and incorporate reasonably anticipatory weather delays into CPM construction schedules, and to enable an owner to appropriately evaluate weather-related time extension requests.

The report explains a methodology for factoring rain-delays into the construction schedule. The procedure used an as-planned network for weather scheduling and an as-built network for time extension evaluation. The as-planned schedule was based on an initial assumption of ideal weather conditions causing no lost time.

Research Tasks

Three tasks were undertaken to achieve the primary objective of the study:

Task One - Develop impact factors to rate construction activities according to their weather sensitivity.

Task Two - Tabulate ten years of historical climatological data for State College, Pennsylvania for use in creation of the model.

Task Three - Create a model to integrate impact factors, historical weather data, and the construction schedule to incorporate anticipated weather delays into the construction plan.

Research Methodology

Three research techniques were used. First, pertinent literature on CPM was reviewed with particular emphasis on how to handle weather-related lost time. The literature search provided background knowledge of the topics of proper CPM scheduling, legal principles behind scheduling and time extensions, and impact factors for sensitivity of construction operations to weather. Second, a sampling of construction contractors, scheduling consultants, and construction management firms were surveyed on how they consider weather in the development of their schedules. Questionnaires were mailed to these firms to gain knowledge of how they consider weather when scheduling, their methods for justifying weather-related time extension requests, and thresholds of rainfall at which decisions are made to stop work. Finally, a model was developed and tested for its ability to include rain delays in the construction plan. Historical climatological data for State College, Pennsylvania was acquired from the National Weather Service for use in model development.

Chapter II

LEGAL ASPECTS OF SCHEDULING WEATHER

Delays in the construction industry are, unfortunately, a way of life. Construction claims for delay are frequently encountered and are among the most complicated for an owner to evaluate. Because of the numerous contractual arrangements between various parties, such as between owner and architect, owner and prime contractor, prime contractor and subcontractors, subcontractors and lower tier subcontractors, and contractors and suppliers, there are numerous opportunities for communication breakdowns, missed-deadlines for decisions and actions, and subsequent delays. Delays might also be caused by strikes, late delivery of materials, changes in design, and adverse weather.

Delay claims instigated by contractors are often of a complex nature and initial requests for equitable adjustments of contract time, cost, or both are often denied, resulting in disputes. The foremost cause of construction claims is not a dispute of liability, but instead, a dispute of facts due to incomplete information [10]. This situation is antagonized by contractor demands and owner settlement offers that are unreasonable. One cause of delay claims that has often resulted in disputes concerns weather. Discussion of the legal aspects of considering weather when preparing construction schedules is pertinent to the development of weather scheduling techniques.

To conduct a meaningful analysis of the legal aspects

of weather scheduling, several tasks were accomplished:

1. Typical Contract Provisions for schedules and time extensions were reviewed and analyzed.
2. Delay Types were identified and classified.
3. Legal Cases involving weather delays were analyzed.

Typical Contract Provisions for Schedules and Time Extensions

Completion of a construction project on schedule is a primary goal shared by owners and contractors alike. To accomplish this objective, construction contracts frequently contain provisions for detailed schedules, for fixing the completion date, and, when necessary, for extending the completion date when unforeseeable delays beyond the control of the contractor occur. When disputes arise over the allowability of a time extension claimed by a contractor, the first step towards claim resolution is a thorough review of the contract documents with particular regard to clauses on scheduling and time extensions.

Scheduling Clauses

Scheduling clauses in a construction contract detail the requirements of the contractor's schedule. A scheduling clause may simply require the submission of a schedule without requirements for format (bar chart, network) or updating frequency (weekly, monthly), or it may be extraordinarily detailed. These clauses can be supplemented with special provisions that assign more stringent scheduling requirements to the contractor. As an example, construction con-

tracts for the Defense Department, the Veteran's Administration, the General Services Administration, and other Federal agencies specify the use of CPM scheduling. These supplemental requirements are listed in the technical provisions of the contract. The allowable number of activities in the network, minimum and maximum allowable activity durations, and restrictions on the number of critical activities are examples of additional requirements created by supplemental contract provisions. Table 1 provides a sampling of commonly used clauses.

In comparing the basic clauses, three factors may be noted. These factors are the time frame within which the schedule is to be submitted, the purpose for schedule submission (for information vs. for approval), and the degree of detail for activity breakdown. As stated previously, special provisions on scheduling may be present in a contract. When present, these provisions typically address the factor of activity breakdown detail. An analysis of these clauses for activity detail requirements is not within the scope of this investigation.

In comparing the three clauses for submission time frame requirements, the American Institute of Architects (AIA) Document A-201 contains the most stringent language. AIA Document A-201 requires schedule submission immediately upon award. The clause from the FAR, on the other hand, does not require schedule submission until within five days after starting work. This can create anxiety for the con-

Table 1
Contract Scheduling Clauses

AIA A-201	EJCDC 1910-8	FAR
4.10 PROGRESS SCHEDULE The Contractor, immediately after being awarded the Contract, shall prepare and submit for the Owner's and Architect's information an estimated progress schedule for the Work. The progress schedule shall be related to the entire Project to the extent required by the Contract Documents, and shall provide for expeditious and practicable execution of the Work.	2.6 Within ten days after the effective Date of Agreement (unless otherwise specified in the General Requirements), CONTRACTOR shall submit to ENGINEER for review: 2.6.1 an estimated progress schedule indicating the starting and completion dates of the various stages of work; 2.6.2 a preliminary schedule of Shop Drawing submissions 2.9 At least ten days before submission the the first Application for Payment a conference attended by CONTRACTOR, ENGINEER and others as appropriate will be held to finalize the schedules submitted in accordance with paragraph 2.6. The finalized progress schedule will be acceptable to ENGINEER as providing an orderly progression of the Work to completion within the Contract Time, but such acceptance will neither impose on ENGINEER responsibility for the progress or scheduling of the Work nor relieve CONTRACTOR from full responsibility therefor. 6.6 CONTRACTOR shall submit to ENGINEER for acceptance (to the extent indicated in paragraph 2.9) adjustments in the progress schedule to reflect the impact thereon of new developments; these will conform generally to the progress schedule then in effect and additionally will comply with any provisions of the General Requirements applicable thereto.	52.236-15 SCHEDULES FOR CONSTRUCTION CONTRACTS (a) The Contractor shall, within five days after the work commences on the contract or another period of time determined by the Contracting Officer, prepare and submit to the Contracting Officer for approval three copies of a practicable schedule showing the order in which the Contractor proposes to perform the work, and the dates on which the Contractor contemplates starting and completing the several salient features of the work (including acquiring materials, plant, and equipment). The schedule shall be in the form of a progress chart of suitable scale to indicate appropriately the percentage of work scheduled for completion by any given date during the period. If the Contractor fails to submit a schedule within the time prescribed, the Contracting Officer may withhold approval of progress payments until the Contractor submits the required schedule.

AIA A-201 - American Institue of Architects Document A-201
EJCDC 1910-8 - Engineers' Joint Contract Documents Committee Document 1910-8
FAR - Federal Acquisition Regulations

tract administrator when the contract allows too much time for completion and a contractor does not plan to start until well into the contract period.

With regard to submission purpose of a schedule, AIA Document A-201 requires only that the schedule be submitted for information. Furthermore, the AIA clause provides no disincentive to a contractor intending to withhold schedule submission. The FAR and the Engineers' Joint Contract Documents Committee (EJCDC) Document 1910-8 both require schedule submission for approval. Of the two, the FAR is more stringent, for it allows the contracting officer to withhold payment should the contractor fail to submit initial or updated schedules.

The contractor must comply with contract requirements for scheduling, regardless of the simplicity or complexity of the scheduling specifications. The contractor, however, is not without options in preparing schedules. His or her options are to prepare a schedule that meets either the minimum contract requirements or the management needs of the contractor. The best choice is to use the type of schedule that is most suitable to the contractor, independent of the contract requirements, for a schedule prepared for the contractors' own purposes need not be submitted to the owner, barring any contract requirements to the contrary [11].

Time Extension Clauses

Construction contracts typically provide a means for the contractor to extend the completion date if the contrac-

tor is delayed by the owner or other designated events. When such delays on a construction project occur, it is vital for the contractor and the owner to review their contract. This review is in order to ensure an understanding of the rights and responsibilities granted by the contract. Depending on the language in the contract, the contractor may be entited to additional time, and possibly additional compensation, should the delay be the owner's fault. Table 2 provides an indication of commonly used clauses for time extensions.

Because jobsite delays and suspensions have often been the root cause of complex and costly litigation, the subtleties of the clauses requires discussion. The FAR clause contains a provision for notice within 10 days of the start of the delay; however, the notice need not be in writing. AIA Document A-201 and EJCDC 1910-8 have written notice provisions. The AIA clause requires notice within 20 days after the start of the delay. The EJCDC clause calls for notice within 60 days from delay commencement. Inspite of the different notice requirements of each of the clauses, the clauses are similar with respect to the listing of events which activate the clause.

Other Clauses

In addition to the primary clauses for scheduling and time extensions, construction contracts may contain other clauses that call out the contractor's responsibility to include normal weather delays in his schedule. For in-

Table 2
Contract Time Extension Clauses

AIA A-201	EJCDC 1910-8	FAR
8.3 DELAYS AND EXTENSIONS OF TIME 8.3.1 If the Contractor is delayed at any time in the progress of the Work by any act or neglect of the Owner or the Architect, or by any employee of either, or by any separate contractor employed by the Owner, or by changes ordered in the Work, or by labor disputes, fire, unusual delay in transportation, adverse weather conditions not reasonably anticipatable, unavoidable casualties, or any causes beyond the Contractor's control, or by delay authorized by the Owner pending arbitration, or by any other cause which the Architect determines may justify the delay, then the Contract Time shall be extended by Change Order for such reasonable time as the Architect may determine.	12.2 The Contract Time will be extended in an amount equal to time lost due to delays beyond the control of CONTRACTOR if a claim is made therefor as provided in paragraph 12.1. Such delays shall include, but not be limited to, acts or neglect by OWNER or others performing additional work as contemplated by Article 7, or to fires, floods, labor disputes, epidemics, abnormal weather conditions or acts of God.	52.249-10 DEFAULT (b) The Contractor's right to proceed shall not be terminated nor the Contractor charged with damages under this clause, if - (1) The delay in completing the work arises from unforeseeable causes beyond the control and without the fault or negligence of the Contractor. Examples of such causes include (i) acts of God or of the public enemy, (ii) acts of the Government in either its sovereign or contractual capacity, (iii) acts of another Contractor in the performance of a contract with the Government, (iv) fires, (v)floods, (vi) epidemics, (vii) quarantine restrictions, (viii) strikes, (ix) freight embargoes, (x) unusually severe weather, or (xi) delays of subcontractors or suppliers at any tier arising from unforeseeable causes beyond the control and without the fault or negligence of both the Contractor

AIA A-201 - American Institue of Architects Document A-201
EJCDC 1910-8 - Engineers' Joint Contract Documents Committee Document 1910-8
FAR - Federal Acquisition Regulations

stance, the FAR contains the following clause:

> (a) The Contractor acknowledges that it has taken steps reasonably necessary to ascertain the nature and location of the work, and that it has investigated and satisfied itself as to the general and local conditions which can affect the work or its costs including, but not limited to, (1) conditions bearing upon transportation, disposal, handling, and storage of materials; (2) the availability of labor, water, electric power, and roads; (3) uncertainties of weather, river stages, tides, or similar physical conditions at the site; (4) the conformation and conditions of the ground; and (5) the character of equipment and facilities needed preliminary to and during work performance [12].

The FAR clause clearly places responsibility for determining weather conditions at the construction site locale with the contractor. In contracts for the state highway departments of Pennsylvania and Texas, a contrasting approach is taken. The number of anticipated productive days per month subject to weather influences are included in published schedules. The PennDOT schedule is indicated in Table 3. These contracts have relieved the contractor of the burden of investigating weather conditions. If the productive day schedule is reasonably accurate, the approach taken by the state highway departments facilitates planning by the contractor and time extension request evaluation by the highway department.

Delay Identification and Classification

To properly resolve delay claims, the delays must be identified and classified. Of these tasks, classification of the delay is generally easier to perform. For example, a delay claim due to a strike is easily differentiated from an owner-caused delay, such as a suspension of work. The

Table 3
PennDOT Schedule of Productive Workdays [13]

Month	Work days	Cumulative work days	Conversion Factor, work days to calendar days	Cumulative calendar days
Jan	2	2	15.500	31
Feb	2	4	14.000	59
Mar	7	11	4.429	90
Apr	12	23	2.500	120
May	18	41	1.722	151
Jun	18	59	1.667	181
Jul	18	77	1.722	212
Aug	18	95	1.722	243
Sep	18	113	1.667	273
Oct	15	128	2.067	304
Nov	5	133	6.000	334
Dec	2	135	15.500	365

identification of delays, on the other hand can be a complex, arduous task.

Identification of Delays

The identification of delays is fundamental to analysis of the claim. For the claim to be successful, strong evidence must be presented by the contractor. The evidence must be based on the actual project records, and it must be presented in a form acceptable to the owner, board or court. Undesirable consequences occur when the claiming party has everything going for its position except the verification of fact [14]. To gather evidence, detailed research of the project records must be performed. For each delay substantiated by the project records, the contractor must:

1. identify each action causing delay
2. identify the party responsible for this action

3. locate this action in the schedule

4. prove the impact of delay

These four steps are mandatory for any delay claim [11].

An instrument used in the identification and presentation of delay evidence is the as-built CPM schedule. Its value in delay claim resolution has been noted in numerous articles and publications [11,15,16,17,18,19,20]. In Chapter 4 of this report, a variation of the network adjustment technique developed by Merrill is used for weather delay claim analysis.

Classification of Delays

Upon completion of delay identification, consideration turns to the remedies available to the contractor under the terms of the contract. Delays may be classified as excusable or non-excusable, depending on whether or not a time extension is allowable. Excusable delays may be sub-divided into excusable/compensable and excusable/noncompensable categories. Examples of these delay types are presented in Table 4.

Excusable Delays. An excusable delay is a delay which directly affects the ultimate completion of construction and occurred through no fault of the contractor. When an excusable delay occurs, the contractor is entitled to an equitable extension of the contract period. The importance of understanding the impact of the delay on the schedule can not be understated. If a contractor seeking a time extension due to an excusable delay fails to establish a connection

Table 4
Principal Types of Delay [21]

Excusable		Nonexcusable
Compensable	Noncompensable	Noncompensable to Contractor and Compensable to Owner
1. Delays Caused by Owner - Lack of coordination - Hold or suspension - Failure to provide access - Owner-furnished material not available - Major change - Delays in approval of change orders, shop drawings, schedules - Stop work order - Inadequate information and supervision 2. Changed Conditions 3. Differing Site Conditions 4. Acceleration - Directed - Constructive	1. Delays Out of Contractor's and Owner's Control - Acts of God - Floods - Public enemy - Other contractors - Sovereign authority - Epidemics - Strikes - Embargoes - Weather - Subcontractors and suppliers	Delays for Which Contractor Is Responsible 1. Subcontractor delay 2. Financial ability 3. Failure to perform - Failure to mobilize and man the job - Poor workmanship - Failure to order materials and equipment - Failure to schedule the work - Inadequate supervision

between the delay and the critical path, relief will not be granted. It also should be noted that an excusable delay may cause the critical path to shift. Also, it is important to identify the cause of an excusable delay, for depending on the type of excusable delay, the contractor may be entitled to financial consideration, as well as a time extension.

1. Excusable/Compensable: These delays occur through acts or omissions of the owner or his agent which interfere with the contractor's progress. Examples of such delays are withholding site access from the contractor or suspending work when the owner experiences cash flow problems. When such circumstances occur, the contractor is entitled to financial compensation for extra costs incurred as well as a time extension.

2. Excusable/Noncompensable: These delays are not the fault of the contractor, the owner, or their agents. The force majeure clauses in the contract single out specific events justifying relief to the contractor, such as acts of God, embargoes, and epidemics. Excusable/noncompensable delays entitle contractors to time extensions only.

Weather delays are considered excusable/noncompensable delays, provided the weather was unusually severe and it affected controlling activities on the schedule. Contractors are not entitled to a time extension when they encounter normal weather. In the remainder of this report, the term "normal weather" and "average weather" will be used

interchangeably.

Nonexcusable Delays. Delays that are the fault of the contractor are nonexcusable. Depending on the contract language, the contractor may also be held liable for delays that are the fault of the subcontractors and suppliers engaged by the contractor. When such delays occur and the project completion is delayed as a result, the owner may be compensated in the form of liquidated damages or actual damages. If the project is still in progress but behind schedule due to nonexcusable delays, the owner may direct the contractor to accelerate or may elect to terminate the contract.

All too often, contractors include no contingency for normal weather delays in their schedules. Consequently, when lost time occurs due to normal weather delays, these delays may also be considered nonexcusable.

Analysis of Legal Cases

A logical approach to developing a method for factoring weather delays into construction schedules is to examine the decisions of our legal system in this regard. Court and Federal Appeal Board decisions have served to endorse CPM as a construction scheduling method and "As-Built" CPM Networks as an acceptable evidentiary tool for delay claim verification. Furthermore, legal decisions have rejected scheduling techniques that fail to establish the interrelationships of activities in a construction schedule.

For weather planning, court decisions govern three

principles affecting the development of a weather scheduling technique. These principles are listed as follows:

1. the method must indicate activity interrelationships.
2. the method must include the impact of reasonably anticipatory weather in the construction schedule.
3. the method must include a sufficient period over which climatological data are evaluated to establish reasonably anticipatory weather.

Legal Recognition of CPM

Courts have emphasized CPM schedules as persuasive evidence of delay and disruption on a construction project. CPM schedules have become the standard vehicle for presentation of construction claims. Bar charts, on the other hand, fail to indicate activity interdependence. This shortcoming renders bar charts unacceptable for determining delay impacts. In the case of Minmar Building, Inc., GSBCA 3430, 72-2 BCA 9599, the Appeal Board noted the superiority of network analyses over bar charts for claim evaluation.

CPM is well-suited for weather scheduling for the same reasons it validates delay claims. Because CPM indicates activity interdependencies, it enables the scheduler to determine the impact of weather-compensated activity durations on controlling and dependant activities.

Legal Responsibility to Consider Weather

In and of itself, bad weather generally does not excuse a contractor's failure to complete work on time. In accord-

ance with the terms of his contract, the contractor is expected to have contemplated the weather conditions at the construction site for the period of performance. In addition, the contractor is expected to have made an appropriate allotment for weather in his construction plan.

Weather for a particular location and time of year can be characterized as falling into one of three categories - ideal, normal, and unusually severe - and the last category is the only basis for a time extension. In the case of DeSombre v. Bickel, 118 N.W.2d 868, the Court stated:

> For example, some bad weather is to be expected. If the contract period is for 400 days, the contractor obviously does not have the right to expect 400 dry, sunny days with all of his subs working at full force [22].

Similarly, in the case of Gross v. Exeter Machine Works, 121 A. 195, the court held that the defendant contractor was not excused when winter snow storms caused a delay in transportation of material to a project site. It was established that the weather was not unusually severe when compared with the usual winter conditions in Northern Pennsylvania. The court noted that winters in that region are expected to be severe and the contractors should consider that when preparing bids [23].

In seeking time extensions for weather, the contractor must not only show the presence of unusually severe weather, but also, he must indicate the extent to which that weather delayed the specific work in progress at the time. As noted in the case Jonathan Woodser Co., ASCBA 4113, 59-1 BCA 2120:

> The key to time extensions for unusually severe weather is not the cause per se, i.e., the weather, but the effect of the unforeseen weather on the work being performed.
>
> In order to apply the standard time extension provisions reasonably it is necessary that the parties consider not only the severity of the weather but the type of work being performed and the effect of the weather on the work.
>
> To determine whether a contractor is entitled to a time extension for unusually severe weather certain facts must be established and criteria met: (1) there must be identification of the work controlling the overall completion of the contract; (2) it must be established that this controlling work was delayed by the weather; and (3) it must be established that the weather was unforeseeable, i.e., unusually severe [17].

The Woodser decision magnifies the ability of CPM schedules to highlight controlling activities. The decision also emphasizes consideration of activity sensitivities to weather effects. By understanding the varying sensitivities of construction activities to weather, impact factors can and should be developed to plan for the effects of normal weather.

Climatological Data Period

With an understanding and development of activity weather impact factors and utilization of CPM for scheduling, the next area of concern is the climatological data period used to define normal weather. With a suitable data period, the average weather over the period can be said to be foreseeable. In the case Joseph E. Bennett Co., GSBCA 2362, 72-1 BCA 9364, the contractor's CPM analysis for various delay claims was rejected. The portion of the claim for weather delay was rejected for a failure to consider foreseeable

weather conditions [15].

Construction claims handbooks and legal cases provide varying guidance on the planning period for climatological data. In Wertheimer Construction Corp. v. United States, 406 F. 1071:

> The contractor claimed that it should not have been penalized for certain of the delay time because the real cause was bad weather, and a suitable request for extension of contract time had been made to the contracting officer. After comparing weather conditions in the region in similar months during a preceding eight year period, the contracting officer granted a 22 day extension for each group. The contractor felt that the period of delay should have been substantially longer. However, the contractor's evidence was found to be vague and intangible, and the trial commissioner found against the contractor on this premise.

In the Wertheimer case, an eight year period was analyzed to determine what constituted normal weather. Handbooks have indicated that a five to ten year period is appropriate [16, 17, 24, 25]. It should be noted that, when evaluating a weather delay claim, there are possible limitations to statistical information provided by the weather bureau or by weather agencies. Many times construction job reports note rain at the site location while weather reports have recorded a clear day in the same area [14].

Summary

The legal aspects of incorporating anticipated weather delays into a construction schedule are one of the primary motivators for contractors to perform such planning. This chapter has detailed the manner in which contracts address schedules and time extensions, types of delays encountered during construction, and legal decisions concerning weather

scheduling. The next chapter will present the methodology for incorporating anticipated weather in the schedule.

Chapter III

THE WEATHER SCHEDULING MODEL

Introduction

The development of the model for scheduling weather has concentrated on ensuring coverage of the legal aspects addressed in Chapter II. In Chapter II, the type of schedule used during presentation of the claim was crucial towards the chances of success. Bar chart presentations were discounted because the charts fail to indicate activity interrelationships. CPM Networks were emphasized because the networks indicate activity interrelationships. By indicating activity interdependancies, CPM networks can show the ultimate impact on the project of delays to any individual activities. In litigation, arbitration, or claims presentations, actual delays are examined in the network. For the model developed in this chapter, the network includes anticipated weather delays, as opposed to actual delays.

Legal Principles behind Model

The Woodser decision mentioned in Chapter II addressed the importance of considering the sensitivity of activities to differing weather conditions during construction planning. The occurrence of unusually severe weather does not automatically entitle a contractor to an extended completion date. Activities that are performed entirely within the confines of an enclosed structure, such as carpet laying, tile setting, and interior painting may display little or no sensitivity to extremes of precipitation, temperature, or

humidity. Given the insensitivity of these and similar activities to weather, weather-based time extension requests would be difficult to justify. Such requests may depend on weather impacts to transportation of workers and material to the construction site, rather than the activities scheduled for performance.

An understanding of activity sensitivities to weather supports the contractor in two ways. First, when the impacts of normal weather are understood, quantified, and incorporated into the schedule, the contractor is better prepared to validate weather-related time extension requests. Second, and more importantly, the contractor prepares more realistic construction plans when he considers and incorporates weather impacts in his schedule than when weather is not accounted for.

The model for scheduling weather delays was developed around the three principles mentioned in Chapter II. To ensure the methodology indicated activity interdependencies, a CPM network was used for scheduling. To develop weather sensitivity factors for activities, separate techniques were used, and the results were analyzed to synthesize overall sensitivity factors per activity. Weather data for State College, Pennsylvania was obtained from N.O.A.A. Additionally, weather data from a private weather service was collected for a brief period to compare with N.O.A.A. weather data.

Detailed Discussion of Existing Models

In Chapter I, existing methods of incorporating weather delays into construction schedules were pointed out and briefly described. The increased activity duration approach was regarded as the most appropriate approach. Additional discussion on the increased activity duration approach provides pertinent background information on the model development. The problem with using this approach is quantifying the amount of duration increase for weather-sensitive activities. The literature researched identified two types of increased activity duration approaches. The first approach used probabilistic weather simulation to determine impacts to activity durations. The second approach to increase activity durations depends on calendar-day algorithms.

Probability Models. In a journal article by Benjamin and Greenwald, weather effects on the schedule were simulated with three separate models [26]. Model one simulated daily weather effects with random weather predictions of controlled accuracy. Decisions to work or not to work were based on the activity's sensitivity to temperature, precipitation, and wind, and the randomly generated weather. In models two and three, the randomly generated weather was replaced by daily probabilities that weather would be suitable for activities underway. In Ahuja and Nandakumars' model [27], daily weather was simulated based on ten years of weather data in a manner similar to model one by Benjamin and Greenwald. These probability-based methods for schedul-

ing weather were considered too sophisticated for the number of small contractors that comprise the construction industry. Furthermore, contractors may be extremely apprehensive in using models that depend in part on randomly generated calculations.

Calendar Day Models. The second approach to increase activity durations depends on calendar-day algorithms. These algorithms recognize that the weather an activity faces is dependent upon the time of year that the activity is performed. Also, weather affecting one activity duration at the construction site also effects concurrent activities because activities progressing simultaneously share the same weather. And, weather affecting one activity duration can also affect durations of following activities because their start times are changed as well as the seasonal weather they face. The revised activity durations are determined by iterative passes through the CPM network. Models developed by O'Shea [8], Shaffer [9], and Carr [28] were based on the calendar day approach; however, each of the models has shortcomings.

In the O'Shea model, adjusted activity durations are determined by the following formula:

$$DUR\ R_2 = DUR\ R_1[1 + (WF)(SF)] \tag{1}$$

where:

WF = weather factor; # of lost days per month divided by # days per month
SF = sensitivity factor between 0 and 1; equals 1 for activities totally dependent on the weather, equals 0 for

activities totally independent of the effects of weather

DUR R_2 = adjusted activity duration in days

DUR R_1 = original activity duration in days

The weakness of this model is that sensitivity factors are arbitrarily determined by means of the planner's construction intuition and experience rather than through research and testing. Shaffer's model is similar to O'Shea's model in that adjusted activity durations are determined as follows:

$$\text{duration}_i = \text{duration}_{ru}/\text{OEF} \tag{1}$$

where:

duration_i = adjusted duration of an activity when it occurs at time i in days

duration_{ru} = duration of an activity occurring at a reference unit in time in days

OEF = Operation Efficiency Factor

Tables 5 and 6 are partial listings of activity data and OEF's to indicate how the method may be applied. The weakness of this model is evident with activities having finish dates in months different from the starting months. Additionally, the operating efficiency factors were unsupported and were provided only for the purpose of demonstrating the technique.

Carr's model applied weather data for a thirty year period to a CPM network. Activities in the network that were considered weather-sensitive were coded with correction factors. Tables 7 and 8 are a partial listing of activity data and correction factors from the Carr model. Daily weather data from the thirty year record was compared with

Table 5
Activities and Durations for Shaffer Model

Operation No.	Description	$Duration_{ru}$ (days)
7	Start	0/May
1	Order/Deliver Rebar	30/May
34	Erect Walls	31/June
29	Clear Site	4/Aug
30	Excavate Footings	4/Sep

Table 6
Operation Efficiency Factors

Opr. No.	J	F	M	A	M	J	J	A	S	O	N	D
1,7	1	1	1	1	1	1	1	1	1	1	1	1
29	.3	.3	.5	.7	.7	.8	.8	1	.9	.8	.6	.4
30	.2	.2	.4	.6	.7	.8	.8	.9	1	.7	.5	.2
34	0	0	.2	.7	.9	1	.9	.9	.9	.9	.6	0

Table 7
Activity Data

Activity No.	Description	Duration (days)
1	Shop Drawings	25.4
2	Tower Foundation Excavation	20.3
6	Footer Forms	10.4
9	Place Footing Concrete	4.5

Table 8
Weather Sensitivity Corrections

Table values represent partial or complete lost daily progress.

Rainfall (inches)	Activity No. 1	2	6	9
>=0.10 over 1 day	0	.5	.5	.5
>=0.25 over 1 day	0	-	1	1
>=0.25 over 2 days	0	1	-	-
>=0.50 over 2 days	0	-	1	1
>=0.50 over 3 days	0	1	-	-
>=1.00 over 7 days	0	1	-	1
>=3.00 over 7 days	0	-	1	-
>=3.00 over 14 days	0	1	-	-
>=5.00 over 14 days	0	-	1	1
>=8.00 over 28 days	0	1	-	-

the sensitivity corrections for activities in progress to determine adjustments to single day activity progress. The single day progress was measured as:

$$\text{single day progress} = 1 - \text{sensitivity correction factor}$$

By this expression, weather associated with correction factors of one causes complete loss of a work day for an activity. When the sum of single day progresses equaled the activities duration of productive work days, referred to by Carr as the 'raw duration', the adjusted activity was computed as the number of working days between the start and finish of the activity.

Carr's model serves as the basis for the model developed by this report. In Carr's simulation, the antici-

pated impact of weather was determined by treating the project as if it occurred in each of the 30 years of historical data subject to weather recorded in each year and averaging the adjusted activity durations. The difficulty with Carr's model occurs in applying the various sensitivity correction factors to activities' single day progress. As an example, a short duration activity, such as Footing Concrete Placement (activity number 9), might lose a single day of progress due to over five inches of rain over a fourteen day period while no rain occurred between the start and finish date of the activity. While the model in this report is similar to Carr's simulation, key differences will be elaborated on later in this chapter.

Computer Software Applications During Model Development

The use of computer hardware and software greatly facilitated development of the model. The various types of software used for schedule calculations, weather data, and recording survey results are discussed below, with particular regard to how the software was applied. Three types of software were required in the course of research: Scheduling/Project Management software, Spreadsheet software, and Data Base Management software.

The scheduling software PRIMAVERA was used to expedite network calculations. The software also solved the problem with the increased activity duration approach of tracking planned versus actual productivity. The method of tracking productive time versus lost time due to weather treats an

activity's weather time as a resource. As lost time occurs due to weather while the project is in progress, the weather resource "actual quantity to date" for applicable activities is updated. In tracking usage of the weather resource, it is necessary to revise the scheduling softwares' rules for resource monitoring. The revision allows manual input of the actual quantity of weather time used to date for an activity. Without revision, the actual quantity to date would have be calculated as follows:

$$\begin{array}{c} \text{actual qty} \\ \text{to date} \end{array} = \begin{array}{c} \text{percent} \\ \text{complete} \end{array} \times \begin{array}{c} \text{budget} \\ \text{qty} \end{array} \tag{4}$$

Ten years of rainfall data for State College, Pennsylvania were assembled for the model by using Lotus 1-2-3. Each data record of daily rainfall contained four fields: year, month, date, and rainfall amount. Trace rainfall readings were input as 0.001 inches and dry days were recorded as 0.000 inches.

Two separate spreadsheets were created and combined during model development. The first spreadsheet, shown in Appendix A, contained rainfall data. The second spreadsheet contained statistical functions for calculating the cumulative frequency of rainfall observations exceeding criterion, the criterion, and a macro command. The macro command in the second spreadsheet was used for retrieving values from the data spreadsheet, performing the statistical calculations, and storing results in separate spreadsheets. Appendix B displays the spreadsheets created by invoking the

macro command in the second spreadsheet. Figure 1 shows one of the spreadsheets created by invoking the macro command in the second spreadsheet. In Figure 1, the spreadsheet indicates the cumulative frequency of rainfall observations exceeding 0.0 inches, 0.1 inches, 0.2 inches and so on through 1.0 inches. For example, Appendix A lists the following rainfall observations for January 2nd in inches: 0.560, 0.000, 0.190, 0.000, 0.000, 0.030, 0.070, 0.001, 1.010, and 0.030. Only one observation is greater than 0.6 inches. The cumulative frequency of rainfall observations greater than 0.2 inches is two. Three observations are greater than 0.1 inches. Seven observations were greater than 0.0 inches. The macro command in the second spreadsheet will calculate the cumulative frequency of rainfall observations with historical rainfall data for any city. To use the macro command properly, the rainfall data must be entered into a spreadsheet in a format similar to the first worksheet.

A survey questionnaire was distributed to local contractors and to contractors, construction managers, and scheduling consultants outside of the local area. The purpose of the questionnaire was to develop background information on methods for scheduling weather, disputes over weather related time extension requests, job records, and rainfall thresholds causing "no work" decisions for various activities. Survey responses were recorded using the database management software, DBase III. By using the retrieve

Day Numbers, January

Rainfall Amount (inches)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.0"	5	7	9	6	7	8	7	10	6	8	10	7	9	8	9	7
0.1"	1	3	1	1	2	1	0	2	1	1	3	1	0	4	4	1
0.2"	1	2	1	1	0	0	0	2	1	0	2	0	0	2	2	1
0.3"	1	2	1	1	0	0	0	2	1	0	1	0	0	1	1	0
0.4"	1	2	0	1	0	0	0	2	1	0	0	0	0	1	1	0
0.5"	0	2	0	1	0	0	0	2	1	0	0	0	0	1	1	0
0.6"	0	1	0	1	0	0	0	2	1	0	0	0	0	1	1	0
0.7"	0	1	0	1	0	0	0	2	1	0	0	0	0	1	0	0
0.8"	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0
0.9"	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1.0"	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Day Numbers, January

Rainfall Amount (inches)	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.0"	6	9	7	5	8	6	7	7	8	7	6	6	9	10	9
0.1"	2	2	2	3	5	0	2	4	2	3	0	0	0	2.	3
0.2"	0	2	0	3	4	0	1	2	2	2	0	0	0	0	1
0.3"	0	1	0	3	4	0	1	0	1	2	0	0	0	0	0
0.4"	0	1	0	3	4	0	1	0	1	2	0	0	0	0	0
0.5"	0	1	0	3	3	0	1	0	1	1	0	0	0	0	0
0.6"	0	1	0	2	3	0	1	0	1	1	0	0	0	0	0
0.7"	0	1	0	2	2	0	1	0	1	1	0	0	0	0	0
0.8"	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0
0.9"	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0
1.0"	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0

Figure 1
Cumulative Frequency of Rainfall Observations for January
in State College, Pennsylvania (1976-1987)

menu option, the survey data bases could be queried to analyze responses.

The Critical Path Network for the Model

The first phase of building the weather scheduling was the creation of an original CPM Network schedule. The schedule was created for demonstration purposes only, and activity durations and interdependency logic were not necessarily indicative of actual project schedules. Problem 7.4 from the Harris text [6] was modified and used as the basic network. Activity durations were lengthened to increase the weather periods reviewed for weather sensitive activities.

The activity durations in the basic CPM network were assumed to be estimated under ideal weather conditions. Activity data are shown in Table 9. A network diagram was created based on Table 9. The diagram is indicated in Figure 2. With the activity data and network, the project was entered into PRIMAVERA. Project holidays for the example are listed in Table 10. The project start was set to begin on 21 September 1987. The schedule determined without weather impacts is indicated in Figure 3.

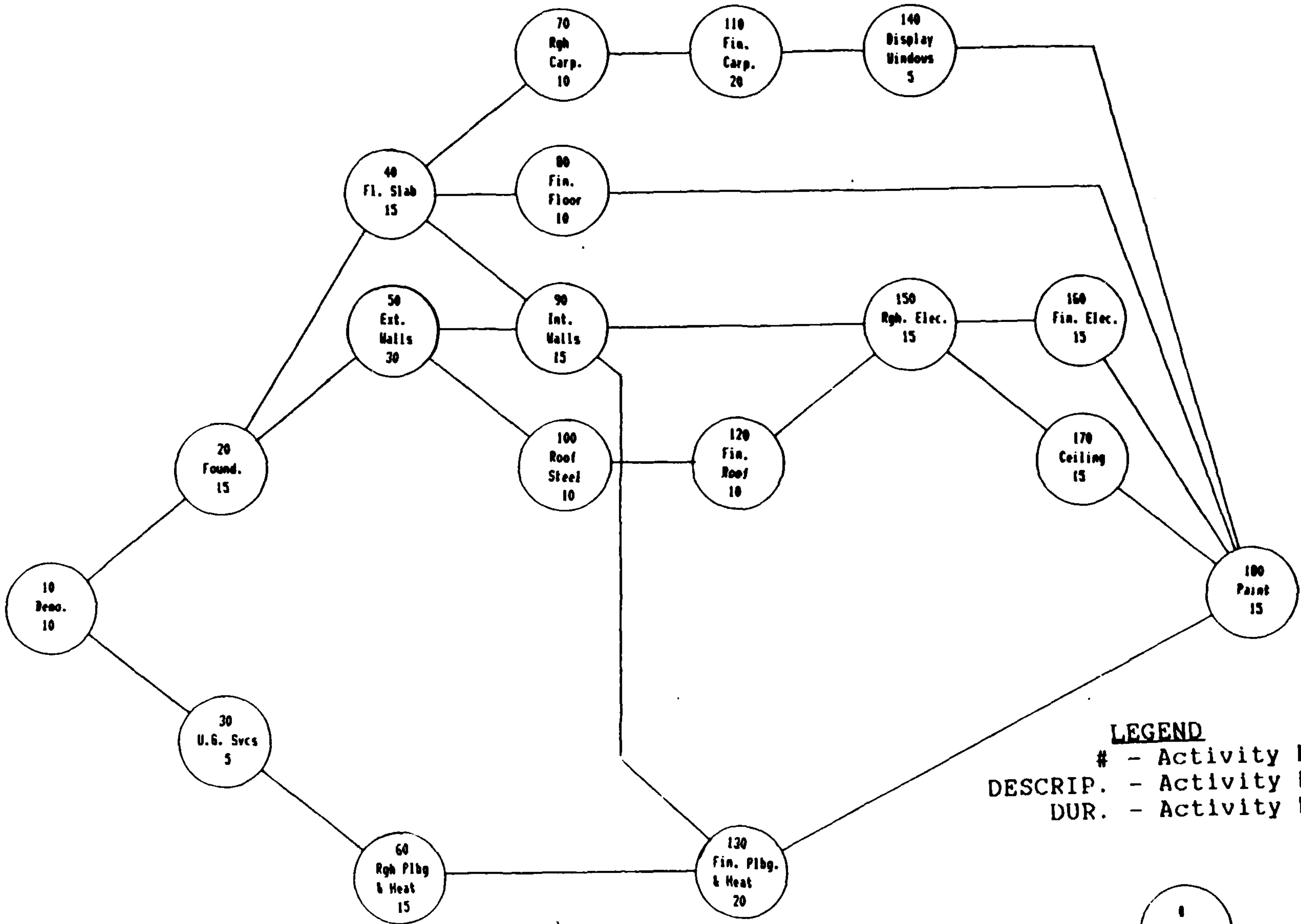
Upon completing the project calendar, two dictionaries were created in PRIMAVERA for the project. The first dictionary was an activity code dictionary. The second dictionary created was a resource dictionary. A single code in the activity code dictionary was made which represents an activity's sensitivity to rain. A single code was made in the resource code dictionary which represents the number of

Table 9
Activity Data For Example Network

No.	Activity	Time (days)	Depends Upon Activity No.
10	Demolition	10	-
20	Foundations	15	10
30	Underground Services	5	10
40	Floor Slab	15	20
50	Exterior Walls	30	20
60	Rough Plumbing and Heating	15	30
70	Rough Carpentry	10	20, 40
80	Floor Finish	10	40
90	Interior Walls	15	40, 50
100	Roof Steel	10	50
110	Finish Carpentry	20	70
120	Roof Finish	10	100
130	Finish Plumbing and	20	60, 90
140	Display Windows	5	110
150	Rough Electrical	15	90, 120
160	Finish Electrical	15	60, 150
170	Ceiling	15	150
180	Paint	15	80, 130, 140, 160, 170

Table 10
Holidays for Example Schedule

Date	Holiday
12 Oct 87	Columbus Day
11 Nov 87	Veteran's Day
26 Nov 87	Thanksgiving
25 Dec 87	Christmas
1 Jan 88	New Year's Day
15 Jan 88	Martin Luther King Day
22 Feb 88	President's Day
15 Apr 88	Good Friday



LEGEND
\# - Activity Number
DESCRIP. - Activity Description
DUR. - Activity Duration, in days

Figure 2
CPM Network Diagram Used for Example

The Pennsylvania State University   PRIMAVERA PROJECT PLANNER   Weather Scheduling Technique

REPORT DATE DDMMMYY RUN NO. XX Variation of Calendar-Day CPM Algorithm START DATE 21SEP87 FIN DATE

SR01 Demo Sched Rep - Sorted by ES, TF   DATA DATE DDMMMYY PAGE NO. 1

ACTIVITY NUMBER	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT
10	10	10	0		Demolition	21SEP87	2OCT87	21SEP87	2OCT87	0
20	15	15	0		Foundations	5OCT87	26OCT87	5OCT87	26OCT87	0
30	5	5	0		Underground Services	5OCT87	9OCT87	24DEC87	31DEC87	55
60	15	15	0		Rough Plumbing and Heating	13OCT87	2NOV87	4JAN88	25JAN88	55
50	30	30	0		Exterior Walls	27OCT87	9DEC87	27OCT87	9DEC87	0
40	15	15	0		Floor Slab	27OCT87	17NOV87	25NOV87	16DEC87	20
70	10	10	0		Rough Carpentry	18NOV87	2DEC87	4JAN88	18JAN88	30
80	10	10	0		Floor Finish	18NOV87	2DEC87	9FEB88	23FEB88	55
110	20	20	0		Finish Carpentry	3DEC87	31DEC87	19JAN88	15FEB88	30
100	10	10	0		Roof Steel	10DEC87	23DEC87	10DEC87	23DEC87	0
90	15	15	0		Interior Walls	10DEC87	31DEC87	17DEC87	8JAN88	5
120	10	10	0		Roof Finish	24DEC87	8JAN88	24DEC87	8JAN88	0
130	20	20	0		Finish Plumbing and Heating	4JAN88	1FEB88	26JAN88	23FEB88	15
140	5	5	0		Display Windows	4JAN88	8JAN88	16FEB88	23FEB88	30
150	15	15	0		Rough Electrical	11JAN88	1FEB88	11JAN88	1FEB88	0
160	15	15	0		Finish Electrical	2FEB88	23FEB88	2FEB88	23FEB88	0
170	15	15	0		Ceiling	2FEB88	23FEB88	2FEB88	23FEB88	0
180	15	15	0		Paint	24FEB88	15MAR88	24FEB88	15MAR88	0

Figure 3
Initial Schedule Calendar Dates for Example

raindays included in an activity's adjusted duration. The rainday resource for an activity is treated the same way other budgeted resources are for updating and monitoring. By updating utilization of the rainday resource, the number of lost days due to rain may be monitored with resource control reports available from the scheduling software, PRIMAVERA.

When activity durations are increased due to anticipated lost rain days, productivity monitoring becomes distorted. By updating an activity's rainday resource, it is possible to segregate lost rain days from productive days. The following equation enables tracking productive days used per activity:

$$\begin{array}{c}\text{Project Day}\\ \text{No. of Actual}\\ \text{Finish Date}\end{array} - \begin{array}{c}\text{Project Day}\\ \text{No. of Actual}\\ \text{Start Date}\end{array} + 1 - \begin{array}{c}\text{Qty}\\ \text{Completion}\\ \text{of rainday}\\ \text{resource}\end{array} = \begin{array}{l}\text{Productive}\\ \text{Days}\\ \text{Used}\end{array} \qquad (5)$$

To demonstrate productivity calculations, an example is provided. The example consists of an activity that started on 9 November 1987 (project day number 34), ended on 20 November 1987 (project day number 42), and consumed two days of the rainday resource. Productive day usage is calculated as follows:

$$42 - 34 + 1 - 2 = 7 \text{ productive days used.}$$

To monitor productivity of an activity in progress, it is necessary to modify the equation as follows:

$$\begin{array}{c} \text{Project Day} \\ \text{No. of Data} \\ \text{Date} \end{array} - \begin{array}{c} \text{Project Day} \\ \text{No. of Actual} \\ \text{Start Date} \end{array} + 1 - \begin{array}{c} \text{to date} \\ \text{of rainday} \\ \text{resource} \end{array} = \begin{array}{c} \text{Productive} \\ \text{Days} \\ \text{Used} \end{array} \qquad (6)$$

Productivity can be calculated by dividing quantities to date by the productive days used to date.

As indicated by Table 9 and Figure 2, the CPM network used was a precedence diagram. The type of network used does not affect the model. Activity duration adjustments under an arrow diagram schedule would be identical to the adjustments under a precedence based network.

Weather Sensitivity Impact Factors

In Chapter II, it was noted that the Woodser Decision emphasizes consideration of activity sensitivities to weather effects. The knowledge of probable weather conditions expected during an activity's scheduled performance dates is of little value, if the activity's sensitivity to weather is not understood. Contractors have the means to develop sensitivity factors. By analyzing daily project records for lost time, a database can be developed of the weather conditions causing lost time (rain, temperature, relative humidity) and the corresponding affected activities.

To develop the model in this report, a carefully developed database was unavailable, so other methods were used to develop activity sensitivity factors. First, broad sensitivity classifications to rainfall were obtained from Russo's guide [7]. Table 11 indicates weather-sensitivity factors by Russo for activities used in the model schedule.

Having established general guidance for rainfall sensi-

Table 11
Weather Sensitivity Factors

Model Activity	Russo Activity	Rain	Low Temp	High Temp	Rel. Hum.
			Weather Sensitivity Values [7]		
Demolition	Demolition and Clearing	M	0 to -10^{0}F	>90^{0}F	THI=77
Foundations	Excavation	M	20 to 32^{0}F	>90^{0}F	THI=77
	Forming	M	0 to -10^{0}F	>90^{0}F	THI=77
	Install Rebar	M	0 to -10^{0}F	>90^{0}F	THI=77
	Pouring Concrete	M	32^{0}F	>90^{0}F	THI=77
	Strip/Cure Concrete	M	32^{0}F	>90^{0}F	THI=77
U.G. Services	Excavation	M	20 to 32^{0}F	>90^{0}F	THI=77
Exterior Walls	Exterior Masonry	L	32^{0}F	>90^{0}F	THI=77
Floor Slab	Forming	M	0 to -10^{0}F	>90^{0}F	THI=77
	Install Rebar	M	0 to -10^{0}F	>90^{0}F	THI=77
	Pouring Concrete	M	32^{0}F	>90^{0}F	THI=77
Roof Steel	Structural Steel	L	10^{0}F	>90^{0}F	THI=77
Roof Finish	Roofing	L	45^{0}F	>90^{0}F	THI=77

L = light rainfall
M = medium rainfall
H = heavy rainfall
THI = temperature humidity index

tivity, it was necessary to quantify rainfall thresholds which halt work activities. Three separate methods were used to define the meaning of light and medium rainfall as classified by Russo. In the first method, eight local contractors with ongoing construction projects at various stages were requested to reply to a survey form and indicate lost work days caused by rainfall during the Fall of 1986. For the second approach, eighty construction, construction

management, and schedule consulting firms were surveyed. These firms were requested to provide information on rainfall amounts that cause work to stop on various activities. The final method involved personally observing ongoing local construction projects during the Spring of 1987. Observations of impacted and unimpacted activities and rainfall amounts were recorded on each day precipitation occurred during working hours. The observations were conducted from 30 March 1987 to 21 May 1987.

Local Contractor Survey

During the Fall of 1986, ten construction projects were active in State College, Pennsylvania. The prime contractor for each of the ten projects was requested to participate in a survey on weather scheduling. Eight contractors volunteered to participate in the research and survey questionnaires were provided to each volunteer. The survey form contained the following questions:

1. What kind of schedule are you using or are required to use on the project?
2. Does your organization schedule weather into your construction schedules?
3. Does your contract allow time extensions for "unusual weather" (or contain similar language)?
4. Have you ever had a project dispute regarding a time extension for weather delays?
5. Do you maintain "lost work day" records?
6. How much rain does it take before you stop work?

7. In the months of October, November, and December 1986, what work days were lost due to weather?

A copy of the survey form is provided in Appendix C. Four of the eight firms responded to the survey.

The survey responses indicated that most of the respondents used bar chart schedules. None of the respondents stated that their construction firms scheduled weather delays into construction plans. For the question concerning contract language, responses were varied. One contractor indicated that his contract addressed weather-related time extensions, and one contractor stated that weather related time was not addressed. The remaining responses were uncertain of the contract language. One contractor had been involved in a project dispute, and all of the contractors responding indicated that "lost day" records were maintained. Responses for lost work days are indicated in Table 12 along with affected activities and rainfall amounts. Although one contractor responded that he maintained lost work day records, he was unable to provide input on lost work days. Sensitivity factors for the local survey were developed by discarding inconsistent low readings and selecting the minimum rainfall amount. Table 13 indicates the local survey sensitivity factors.

Two of the contractors were interviewed to determine their reasons for neglecting weather considerations when scheduling. One contractor indicated that tight scheduling practices allowed no contingency time between the schedule

Table 12
Local Survey Lost Rain Days

Date	Respondent #1	#2	#3	#4	NOAA recorded rainfall (inches)
3 Oct 86				str.stl.	0.73
13 Oct 86	str.stl.				0.60
14 Oct 86	str.stl. masonry				0.03
5 Nov 86	str.stl. masonry	excav.		str.stl.	0.41
11 Nov 86		excav.			0.22
21 Nov 86		excav.			trace
26 Nov 86				str.stl.	1.28
2 Dec 86				str.stl.	0.73
15 Dec 86	str.stl. masonry forming				0.00
16 Dec 86	str.stl. masonry, forming				0.00
24 Dec 86	str.stl. masonry, forming	excav.			0.80
26 Dec 86				str.stl.	trace

Table 13
Local Survey Sensitivity Factors

Activity	Rainfall on lost work days (inches)	factor* (inches)
structural steel	.73, .60, .41, 1.28, .73, .80	.41
masonry	.41, .80	.41
concrete formwork	.80	.80
excavation	.41, .22	.22

* minimum of rainfall, in inches, on lost work days

completion dates and contract completion dates. Another respondent pointed out that weather records were not kept and that bar chart scheduling usually left enough slack to compensate for lost weather time.

Non Local Survey

Because of the limited number of responses to the initial survey, a second survey was undertaken. This survey involved contractors, construction managers, and scheduling consultants in the mid-Atlantic region. The non-local survey was similar to the local survey with the following additional questions:

1. If lost weather time is included in your construction schedules, how is it incorporated?
2. If lost weather time is not included in your construction schedules, what are your reasons for excluding it?
3. If you have been involved in a dispute over a weather related time extension, how did you justi-

fy your position?

4. How much rain does it take before you decide to stop work on the following activities:

-clearing and grubbing?
-earthwork and excavation?
-foundation concrete?
-concrete slabs?
-structural steelwork?
-exterior masonry?
-roofing?
-exterior painting?
-wooden framing?
-asphalt paving?

A copy of the survey form is included in Appendix D. Of the eighty firms surveyed, 48% responded to some or all of the survey questions. Weather was considered during scheduling by 80% of the respondents. For organizations that considered scheduling, survey answers showed the following approaches:

7% use less than five-day work weeks.

14% add contingency time at the end of the schedule.

54% increase the durations of weather sensitive activities.

15% increase activity durations and add contingency time at the end of the schedule.

5% use shortened work weeks, add contingency time at the end of the schedule, and increase activity durations.

5% phase construction during October/April time frame.

When weather wasn't considered during scheduling, survey responses revealed:

17% felt excusable delays due to design errors and omissions compensated for failing to consider weather.

34% said that design error and omission delays compensated for weather delays, and that scheduling handbooks do not adequately demonstrate procedures for scheduling weather.

17% stated that weather scheduling was omitted to gain a competitive edge when bidding work.

17% stated that contract specifications allowed time extensions for all lost weather days, similar to time granted for labor disputes and strikes.

17% felt that, due to the difficulty in assessing the combined impact of rain, temperature, humidity, and wind, scheduling weather was beyond the firms capabilities.

It should be noted that almost 70% of these firms were involved in disputes over weather-related time extension requests. Eighty four percent of the companies had contracts that allowed time extensions for unusually severe weather. Nine percent were involved in contracts that did not allow such time extensions. Six percent of the respondents were unsure of the contract language. Fifty nine percent of the respondents had been involved in disputes over weather-related time extensions.

The survey requested information on how the respondent defends his or her position in disputes over weather related

time extension requests. The survey showed the following methods used by contractors to justify their positions in such disputes:

18% demonstrate that delayed work was on the critical path.

10% demonstrate that controlling work was delayed by weather rather than some fault of the contractor.

10% identify the unusual severity of the weather.

5% prove that delayed work was on the critical path and that weather caused the delay.

10% prove that weather was the cause of delay and that the weather was unusually severe.

47% prove that delayed work was on the critical path, weather caused the delay, and the weather was unusually severe.

Ninety four percent of the respondents claimed to maintain lost work day records.

The responses to the survey question on rainfall thresholds were used to create an alternate set of sensitivity or impact factors. Table 14 depicts the response breakdown and the sensitivity factors developed. Most of "other" responses in Table 14 stated that stop work decisions were based on rainfall intensity rather that specific amounts of rainfall. This is a logical response when day-to-day management of ongoing construction is considered. However, from a construction claims standpoint, insufficient historical data are available for rainfall intensities, and claims tend to

Table 14
Non Local Survey Sensitivity Factors

Activity	Percentage of responses for rainfall ranges 0.000"-0.125"	0.125"-0.250"	0.250"-0.500"	>0.500"	other	mean
clearing and grubbing	10	19	26	19	26	0.313"
earthwork/excavation	15	19	33	7	26	0.278"
foundation concrete	18	31	29	4	18	0.239"
concrete slabs	82	0	0	4	14	0.081"
structural steel	57	7	14	4	18	0.147"
exterior masonry	42	23	12	4	19	0.164"
roofing	81	0	0	4	15	0.082"
exterior painting	80	4	0	4	12	0.087"
wooden framing	22	40	19	4	15	0.209"
asphalt paving	42	35	0	4	19	0.137"

emphasize rainfall amounts.

Personal Observations of Local Construction

The final approach used to quantify weather sensitivity factors created by Russo involved visually observing five different sites. Observations were made between 30 March 1987 and 21 May 1987 on days when rain occurred. Rainfall amounts, affected activities, and unaffected activities were recorded. The results are indicated in Table 15.

The visual survey of local construction was marginally conclusive in establishing impact factors. Contractors at two of the construction sites operated under very tight schedules. Consequently, they often worked on days where rain forced a halt at other sites. The sensitivity factors resulting from the visual survey are indicated in Table 16.

Synthesis of Results from Surveys

To develop sensitivity factors specific to the model,

Table 15
Visual Survey of Local Construction

Date	Activities Affected By Rain at Construction Sites					Recorded Rainfall (inches)
	site A	site B	site C	site D	site E	
30 Mar 87	masonry	formwork	masonry	masonry	masonry	1.06
31 Mar 87	masonry		masonry	masonry	masonry	0.47
6 Apr 87	masonry		masonry, concrete, roughin plumbing	masonry		0.51
17 Apr 87	masonry		masonry	masonry		0.05
24 Apr 87	masonry		masonry	masonry	masonry	0.14

Table 16
Visual Survey Sensitivity Factors

Activity	Rainfall on lost work days	sensitivity* factor (inches)
exterior masonry	1.06, 0.47, 0.51, 0.05, 0.14	0.14
concrete formwork	1.06	1.06
CIP concrete	0.51	0.51
Roughin plumbing	0.51	0.51

* minimum on rainfall, in inches, on lost work days

Note: the rainfall reading of 0.05 inches was considered inconsistent and disregarded in establishing the sensitivity factor for masonry.

the results from each of the surveys were tabulated and compared. Table 17 provides the results and the overall factors developed. The overall factors developed were based almost entirely on the results of the non-local survey rounded to the nearest 0.05 inches. There were three reasons for discounting some of the factors from the local or visual surveys, or both. First, for the activities Founda-

Table 17
Comparison of Results of Surveys

Activities from Model	Russo factors	Local survey factors	Non Local survey factors	Visual survey factors	Overall factor
Demolition	Medium	-	0.313"	-	0.30"
Foundations	Medium	0.80"	0.278"	1.06"	0.30"
U.G. Services	Medium	-	0.278"	0.51"	0.30"
Ext. Walls	Light	0.41"	0.164"	0.14"	0.15"
Floor Slab	Medium	-	0.081"	-	0.10"
Roof Steel	Light	0.41"	0.147"	-	0.15"
Roof Finish	Light	-	0.082"	-	0.10"

tions and U.G. Services, the local and visual survey factors were based on a single precipitation observation. Second, for the activity Exterior Walls, the local survey factor was inconsistent with the non-local and visual survey factors. Finally, for Roof Steel, the local survey factor conflicted with the non-local survey factor and Russo's recommended factor. One conflict was noted between research results for Floor Slab sensitivity to rain and Russo's recommended factor. The research results showed Floor Slabs to be more sensitive to rain than reported by Russo. One possible

explanation for this discrepancy is that Russo may have also considered slabs that were partially and fully sheltered from rainfall.

The overall sensitivity factors for the model were incorporated into the schedule. Factors were entered under the activity code for applicable activities with PRIMAVERA. Also, the second spreadsheet was altered to count rain days from the first spreadsheet based on the overall factors.

Climatological Data

With impact factors and a CPM schedule created for the model, the next phase of development focused on climatological data. Climatological information can serve a useful purpose for long-term planning and bidding. If an accurate indication of the average number of lost days for weather-sensitive operations was available, competitive bidding could be improved. An accurate projection of lost work days would guide the contractor in planning for overtime requirements and potential liquidated damages.

Weather data are available from the U. S. Weather Bureau and private meteorological organizations. Although information in U. S. Weather Bureau data may not be in the format desired by contractors, a moderate effort in data compilation can alleviate this problem.

An alternative to collecting and tailoring U. S. Weather Bureau reports is to utilize private weather bureaus. One such company offers a weather data base that functions similar to a news retrieval service [29]. Customers can

dial up the service and obtain data using a phone modem and personal computer. The data base contains 15,000 different types of weather report data from a variety of sources in over 140 countries. Because private weather organizations are accustomed to tailoring weather data information to customer needs, there are advantages to using a private source. The contractor can save time by not having to create his own custom-tailored database. Also, the private organization can provide guidance on typical weather data needs. There is a trade-off in using a private weather organization to acquire pertinent weather information. Private weather report data are more expensive than NOAA data. Contractors should perform a cost/benefit analysis to choose between public and private weather information sources.

An important consideration in choosing between public and private weather organizations for information is the reliability of the data. Table 18 compares rainfall recordings from both private and public weather bureaus for State College, Pennsylvania. There are numerous discrepancies between the recordings. A contractor might choose to rely on weather information from an organization whose data correlates with rainfall recorded on site. The contractor could either install and monitor a single rain gauge within the construction site, or maintain several rain gauges around the site and average readings from all gauges for the daily rainfall amount.

Table 18
Comparison of U.S. Weather Bureau
Daily Rain Recordings (inches) with
Private Weather Organization Recordings

March 1987	NOAA /(PSU)	Accu Weather	April 1987	NOAA /(PSU)	Accu Weather
1 Mar 87	0.410	0.660	1 Apr 87	0.470	0.000
2 Mar 87	0.140	0.001	2 Apr 87	0.001	0.000
3 Mar 87	0.120	0.070	3 Apr 87	0.060	0.050
4 Mar 87	0.001	0.001	4 Apr 87	0.840	1.100
5 Mar 87	0.001	1.040	5 Apr 87	0.540	0.310
6 Mar 87	0.000	0.180	6 Apr 87	0.410	0.000
7 Mar 87	0.000	0.700	7 Apr 87	0.510	0.000
8 Mar 87	0.000	0.110	8 Apr 87	0.110	0.000
9 Mar 87	0.000	0.000	9 Apr 87	0.000	0.000
10 Mar 87	0.000	0.000	10 Apr 87	0.000	0.000
11 Mar 87	0.000	0.000	11 Apr 87	0.000	0.000
12 Mar 87	0.000	0.070	12 Apr 87	0.060	0.000
13 Mar 87	0.000	0.270	13 Apr 87	0.310	0.010
14 Mar 87	0.000	0.050	14 Apr 87	0.050	0.000
15 Mar 87	0.270	0.000	15 Apr 87	0.000	0.000
16 Mar 87	0.000	0.001	16 Apr 87	0.010	0.230
17 Mar 87	0.000	0.020	17 Apr 87	0.170	0.000
18 Mar 87	0.000	0.210	18 Apr 87	0.050	0.000
19 Mar 87	0.000	0.020	19 Apr 87	0.020	0.060
20 Mar 87	0.000	0.000	20 Apr 87	0.020	0.510
21 Mar 87	0.001	0.030	21 Apr 87	0.030	0.000
22 Mar 87	0.001	0.000	22 Apr 87	0.000	0.000
23 Mar 87	0.001	0.000	23 Apr 87	0.000	0.000
24 Mar 87	0.000	0.000	24 Apr 87	0.490	0.000
25 Mar 87	0.000	0.700	25 Apr 87	0.140	0.000
26 Mar 87	0.260	0.000	26 Apr 87	0.000	0.000
27 Mar 87	0.000	0.000	27 Apr 87	0.000	0.000
28 Mar 87	0.001	0.000	28 Apr 87	0.300	0.000
29 Mar 87	0.001	0.330	29 Apr 87	0.030	0.000
30 Mar 87	0.001	0.000	30 Apr 87	0.001	0.000
31 Mar 87	1.060	0.000			

NOAA/(PSU) - precipitation data recorded by the Pennsylvania State University Meteorology Department for the U.S. Weather Bureau

Accu Weather - a private weather company headquartered in State College, Pennsylvania

Published climatological information from the U. S. Weather Bureau are data collected at hundreds of stations spread across the country. Depending on the type of station, data are observations of temperature, precipitation, wind, and relative humidity. Many stations are limited to recording daily precipitation amounts, and minimum and maximum temperatures. One climatological report available from the weather bureau provides normal, mean, and extremes values, and mean number of days for temperature and rain by month per station.

While the model developed and described in this report can be expanded to consider temperature and relative humidity values to which an activity may be sensitive, rain was the only factor considered to simplify demonstration of how the model functions. For this demonstration, ten years of daily rain data were organized using spreadsheet software. The data were organized according to the calendar dates for the model network schedule and sensitivity factors. Table 19 demonstrates data organization. A review of Table 19 shows that there were two readings greater than 0.10", two readings greater than 0.15" and no readings greater than 0.30". The summary at the foot of Table 19 provides this tabulation. Appendix E displays the final organization of rain data for the model. The appendix parallels the duration of the model schedule with weekends and holidays readings removed.

Table 19
Explanation of Model Rain Data Organization in Appendix E

	Rainfall Observation
21 Sep 76	0.250"
21 Sep 77	0.010"
21 Sep 78	0.000"
21 Sep 79	0.050"
21 Sep 80	0.000"
21 Sep 81	0.000"
21 Sep 82	0.000"
21 Sep 83	0.000"
21 Sep 85	0.000"
21 Sep 86	0.160"
cumulative frequency of observations greater than 0.10 inches	2
cumulative frequency of observations greater than 0.15 inches	2
cumulative frequency of observations greater than 0.30 inches	0

The Weather Scheduling Algorithm

To successfully incorporate the impacts of weather on a schedule, climatological data, sensitivity factors, and the schedule must be combined. A simple example to demonstrate the combination used in the model follows. The example consists of a network comprised of a single activity. The activity has an unimpacted duration of 7 days and is sensitive to rainfall of 0.10 inches or greater. The early start schedule is assumed as the target schedule, and the activities' early start and finish dates are 21 September 1987 and 29 September 1987, respectively. The information below is excerpted from Appendix E:

Sep	21	22	23	24	25	28	29
# > 0.10"	2	2	1	2	1	2	1

The summation of the values 2, 2, 1, 2, 1, 2, and 1 equals 11. Therefore, ten years of historical data covering the activity's period of performance indicate a total of eleven lost work days. The average number of lost work days per year equals one-tenth of the total lost work days for the ten year period considered. The number of rain days to add to the activity is:

$$\frac{\text{11 lost work days over 10 years}}{\text{10 years}} = 1.1 \sim 1 \text{ lost work day/yr}$$

To compensate for anticipated weather delays, the activity's duration is increased by one day from seven to eight days. Now that the activity finish date has been revised to September 30th, this new finish calendar date must also be considered:

Sep	21	22	23	24	25	28	29	30
# > 0.10"	2	2	1	2	1	2	1	0

As indicated above, the new calendar finish date did not affect the cumulative number of lost rain days.

In the simplified example, there were no successor activities affected by the duration increase. In the network used for the model, the increase of an activity's duration affects the start and finish dates of successor activities. Consequently, an iterative process is needed to incorporate the effects of weather over the entire schedule. The adjustment of activity durations is accomplished through

the following steps:

Step One - calculate the schedule with no allowance for weather. The schedule should be sorted according to early start dates.

Step Two - proceed through the schedule chronologically by early start dates until a weather-sensitive activity is encountered.

Step Three - calculate the lost rain days for the weather-sensitive activity in the same manner as the single-activity example described earlier.

Step Four - update the activity duration, description, and log to reflect rain days. Update the rainday resource budget amount to reflect rain days.

Step Five - repeat steps three and four for weather-sensitive activities with the same early start date.

Step Six - recalculate the schedule when all weather-sensitive activities at that particular early start date have been adjusted to determine the impact on successor activities.

Step Seven - repeat step two, proceeding chronologically by early start date from the last adjusted activity. Continue until all weather-sensitive activities have been examined.

Adjustment Process

With organized climatological data, a determination of impact or sensitivity factors for appropriate activities,

and a knowledge of the algorithm steps and the method for calculating lost rain days shown in the single activity example, one can begin the adjustment process.

First Iteration. With the schedule from Figure 3, page 42, the first step in adjusting the network requires identifying by early start date the first scheduled weather-sensitive activity. This corresponds to step two in the algorithm. In Figure 4, page 64, the first weather-sensitive activity is number 10, "Demolition". By step three, it is calculated that one lost rain day can be expected between 21 September 1987 and 2 October 1987. From step four, activity 10's duration, description, log, and resource are updated. Step five is not applicable. In step six, the schedule is recalculated based on the new duration for activity 10. Figure 5 displays the new information. Because activity 10 was on the critical path, the duration increase extended the project by one day. Step seven leads to the second iteration.

Second Iteration. Moving down the activity list from "Demolition" in Figure 5, the next rain-sensitive activity is number 20, "Foundations", starting on 6 October 1987. From steps three and four of the algorithm, two lost rain days are calculated and the activity is updated appropriately. Step five requires an examination of activity 30, "Underground Services", which is also rain-sensitive and starts on 6 October 1987. Although no lost rain days were calculated for activity 30, it is still necessary to update

The Pennsylvania State University PRIMAVERA PROJECT PLANNER Weather Scheduling Technique

REPORT DATE DDMMMYY RUN NO. XX Variation of Calendar-Day CPM Algorithm START DATE 21SEP87 FIN DATE

SR01 Demo Sched Rep - Sorted by ES, TF DATA DATE DDMMMYY PAGE NO. 1

ACTIVITY NUMBER	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT
10	10	10	0		Demolition	21SEP87	2OCT87	21SEP87	2OCT87	0
20	15	15	0		Foundations	5OCT87	26OCT87	5OCT87	26OCT87	0
30	5	5	0		Underground Services	5OCT87	9OCT87	24DEC87	31DEC87	55
60	15	15	0		Rough Plumbing and Heating	13OCT87	2NOV87	4JAN88	25JAN88	55
50	30	30	0		Exterior Walls	27OCT87	9DEC87	27OCT87	9DEC87	0
40	15	15	0		Floor Slab	27OCT87	17NOV87	25NOV87	16DEC87	20
70	10	10	0		Rough Carpentry	18NOV87	2DEC87	4JAN88	18JAN88	30
80	10	10	0		Floor Finish	18NOV87	2DEC87	9FEB88	23FEB88	55
110	20	20	0		Finish Carpentry	3DEC87	31DEC87	19JAN88	15FEB88	30
100	10	10	0		Roof Steel	10DEC87	23DEC87	10DEC87	23DEC87	0
90	15	15	0		Interior Walls	10DEC87	31DEC87	17DEC87	8JAN88	5
120	10	10	0		Roof Finish	24DEC87	8JAN88	24DEC87	8JAN88	0
130	20	20	0		Finish Plumbing and Heating	4JAN88	1FEB88	26JAN88	23FEB88	15
140	5	5	0		Display Windows	4JAN88	8JAN88	16FEB88	23FEB88	30
150	15	15	0		Rough Electrical	11JAN88	1FEB88	11JAN88	1FEB88	0
160	15	15	0		Finish Electrical	2FEB88	23FEB88	2FEB88	23FEB88	0
170	15	15	0		Ceiling	2FEB88	23FEB88	2FEB88	23FEB88	0
180	15	15	0		Paint	24FEB88	15MAR88	24FEB88	15MAR88	0

Figure 4
Original Schedule

The Pennsylvania State University PRIMAVERA PROJECT PLANNER Weather Scheduling Technique

REPORT DATE DDMMMYY RUN NO. XX Variation of Calendar-Day CPM Algorithm START DATE 21SEP87 FIN DATE

SR01 Demo Sched Rep - Sorted by ES, TF DATA DATE DDMMMYY PAGE NO. 1

ACTIVITY NUMBER	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT
10	11	11	0	0.30"	Demolition (1 WD)	21SEP87	5OCT87	21SEP87	5OCT87	0
20	15	15	0	0.30"	Foundations	6OCT87	27OCT87	6OCT87	27OCT87	0
30	5	5	0	0.30"	Underground Services	6OCT87	13OCT87	28DEC87	4JAN88	55
60	15	15	0		Rough Plumbing and Heating	14OCT87	3NOV87	5JAN88	26JAN88	55
50	30	30	0	0.15"	Exterior Walls	28OCT87	10DEC87	28OCT87	10DEC87	0
40	15	15	0	0.10"	Floor Slab	28OCT87	18NOV87	27NOV87	17DEC87	20
70	10	10	0		Rough Carpentry	19NOV87	3DEC87	5JAN88	19JAN88	30
80	10	10	0		Floor Finish	19NOV87	3DEC87	10FEB88	24FEB88	55
110	20	20	0		Finish Carpentry	4DEC87	4JAN88	20JAN88	16FEB88	30
100	10	10	0	0.15"	Roof Steel	11DEC87	24DEC87	11DEC87	24DEC87	0
90	15	15	0		Interior Walls	11DEC87	4JAN88	18DEC87	11JAN88	5
120	10	10	0	0.10"	Roof Finish	28DEC87	11JAN88	28DEC87	11JAN88	0
130	20	20	0		Finish Plumbing and Heating	5JAN88	2FEB88	27JAN88	24FEB88	15
140	5	5	0		Display Windows	5JAN88	11JAN88	17FEB88	24FEB88	30
150	15	15	0		Rough Electrical	12JAN88	2FEB88	12JAN88	2FEB88	0
160	15	15	0		Finish Electrical	3FEB88	24FEB88	3FEB88	24FEB88	0
170	15	15	0		Ceiling	3FEB88	24FEB88	3FEB88	24FEB88	0
180	15	15	0		Paint	25FEB88	16MAR88	25FEB88	16MAR88	0

Figure 5
Schedule After First Iteration

activity information for this activity. By doing so, the schedule provides evidence that historical weather was considered and predicted to have no effect on this activity. Also, it is important to examine the possible duration increases of critical and non-critical activities, for adjustments to non-critical activities could shift the critical path. The third iteration starts after recalculating the schedule in this iteration.

Third Iteration. In Figure 6, the next rain-sensitive activity is number 50, "Exterior Walls". Activity 60, "Rough Plumbing and Heating" was skipped because it was not assumed to be weather sensitive. Six rain days were calculated for activity 50 and three days were calculated for activity 40, "Floor Slab". Schedule recalculation completes this iteration.

Fourth Iteration. From Figure 7, activity number 100, "Roof Steel" is considered next, because activities 70, 80, and 110 are assumed to be insensitive to rain. Activity 100 is estimated to require one weather day, and appropriate adjustments are made to the activity information prior to schedule recalculation. Note that the solid line in Figure 8 beneath activity 90 denotes the last activity considered during the iteration.

Fifth Iteration. As indicated in Figure 8, activity 120, "Roof Finish" is the only activity considered in this iteration. Two lost rain days are calculated for activity 120. Because the remaining activities are assumed to be

The Pennsylvania State University PRIMAVERA PROJECT PLANNER Weather Scheduling Technique

REPORT DATE DDMMMYY RUN NO. XX Variation of Calendar-Day CPM Algorithm START DATE 21SEP87 FIN DATE

SR01 Demo Sched Rep - Sorted by ES, TF DATA DATE DDMMMYY PAGE NO. 1

ACTIVITY NUMBER	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT
10	11	11	0	0.30"	Demolition (1 WD)	21SEP87	5OCT87	21SEP87	5OCT87	0
20	17	17	0	0.30"	Foundations (2 WD)	6OCT87	29OCT87	6OCT87	29OCT87	0
30	5	5	0	0.30"	Underground Services (0 WD)	6OCT87	13OCT87	30DEC87	6JAN88	57
60	15	15	0		Rough Plumbing and Heating	14OCT87	3NOV87	7JAN88	28JAN88	57
50	30	30	0	0.15"	Exterior Walls	30OCT87	14DEC87	30OCT87	14DEC87	0
40	15	15	0	0.10"	Floor Slab	30OCT87	20NOV87	1DEC87	21DEC87	20
70	10	10	0		Rough Carpentry	23NOV87	7DEC87	7JAN88	21JAN88	30
80	10	10	0		Floor Finish	23NOV87	7DEC87	12FEB88	26FEB88	55
110	20	20	0		Finish Carpentry	8DEC87	6JAN88	22JAN88	18FEB88	30
100	10	10	0	0.15"	Roof Steel	15DEC87	29DEC87	15DEC87	29DEC87	0
90	15	15	0		Interior Walls	15DEC87	6JAN88	22DEC87	13JAN88	5
120	10	10	0	0.10"	Roof Finish	30DEC87	13JAN88	30DEC87	13JAN88	0
130	20	20	0		Finish Plumbing and Heating	7JAN88	4FEB88	29JAN88	26FEB88	15
140	5	5	0		Display Windows	7JAN88	13JAN88	19FEB88	26FEB88	30
150	15	15	0		Rough Electrical	14JAN88	4FEB88	14JAN88	4FEB88	0
160	15	15	0		Finish Electrical	5FEB88	26FEB88	5FEB88	26FEB88	0
170	15	15	0		Ceiling	5FEB88	26FEB88	5FEB88	26FEB88	0
180	15	15	0		Paint	29FEB88	18MAR88	29FEB88	18MAR88	0

Figure 6
Schedule After Second Iteration

The Pennsylvania State University PRIMAVERA PROJECT PLANNER Weather Scheduling Technique

REPORT DATE DDMMMYY RUN NO. XX Variation of Calendar-Day CPM Algorithm START DATE 21SEP87 FIN DATE

SR01 Demo Sched Rep - Sorted by ES, TF DATA DATE DDMMMYY PAGE NO. 1

ACTIVITY NUMBER	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT
10	11	11	0	0.30"	Demolition (1 WD)	21SEP87	5OCT87	21SEP87	5OCT87	0
20	17	17	0	0.30"	Foundations (2 WD)	6OCT87	29OCT87	6OCT87	29OCT87	0
30	5	5	0	0.30"	Underground Services (0 WD)	6OCT87	13OCT87	8JAN88	14JAN88	63
60	15	15	0		Rough Plumbing and Heating	14OCT87	3NOV87	18JAN88	5FEB88	63
50	36	36	0	0.15"	Exterior Walls (6 WD)	30OCT87	22DEC87	30OCT87	22DEC87	0
40	18	18	0	0.10"	Floor Slab (3 WD)	30OCT87	25NOV87	4DEC87	30DEC87	23
70	10	10	0		Rough Carpentry	27NOV87	10DEC87	18JAN88	29JAN88	33
80	10	10	0		Floor Finish	27NOV87	10DEC87	23FEB88	7MAR88	58
110	20	20	0		Finish Carpentry	11DEC87	11JAN88	1FEB88	29FEB88	33
100	10	10	0	0.15"	Roof Steel	23DEC87	7JAN88	23DEC87	7JAN88	0
90	15	15	0		Interior Walls	23DEC87	14JAN88	31DEC87	22JAN88	5
120	10	10	0	0.10"	Roof Finish	8JAN88	22JAN88	8JAN88	22JAN88	0
140	5	5	0		Display Windows	12JAN88	19JAN88	1MAR88	7MAR88	33
130	20	20	0		Finish Plumbing and Heating	18JAN88	12FEB88	8FEB88	7MAR88	15
150	15	15	0		Rough Electrical	25JAN88	12FEB88	25JAN88	12FEB88	0
160	15	15	0		Finish Electrical	15FEB88	7MAR88	15FEB88	7MAR88	0
170	15	15	0		Ceiling	15FEB88	7MAR88	15FEB88	7MAR88	0
180	15	15	0		Paint	8MAR88	28MAR88	8MAR88	28MAR88	0

Figure 7
Schedule After Third Iteration

The Pennsylvania State University PRIMAVERA PROJECT PLANNER Weather Scheduling Technique

REPORT DATE DDMMMYY RUN NO. XX Variation of Calendar-Day CPM Algorithm START DATE 21SEP87 FIN DATE

SR01 Demo Sched Rep - Sorted by ES, TF DATA DATE DDMMMYY PAGE NO. 1

ACTIVITY NUMBER	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT
10	11	11	0	0.30"	Demolition (1 WD)	21SEP87	5OCT87	21SEP87	5OCT87	0
20	17	17	0	0.30"	Foundations (2 WD)	6OCT87	29OCT87	6OCT87	29OCT87	0
30	5	5	0	0.30"	Underground Services (0 WD)	6OCT87	13OCT87	11JAN88	18JAN88	64
60	15	15	0		Rough Plumbing and Heating	14OCT87	3NOV87	19JAN88	8FEB88	64
50	36	36	0	0.15"	Exterior Walls (6 WD)	30OCT87	22DEC87	30OCT87	22DEC87	0
40	18	18	0	0.10"	Floor Slab (3 WD)	30OCT87	25NOV87	7DEC87	31DEC87	24
70	10	10	0		Rough Carpentry	27NOV87	10DEC87	19JAN88	1FEB88	34
80	10	10	0		Floor Finish	27NOV87	10DEC87	24FEB88	8MAR88	59
110	20	20	0		Finish Carpentry	11DEC87	11JAN88	2FEB88	1MAR88	34
100	11	11	0	0.15"	Roof Steel (1 WD)	23DEC87	8JAN88	23DEC87	8JAN88	0
90	15	15	0		Interior Walls	23DEC87	14JAN88	4JAN88	25JAN88	6
120	10	10	0	0.10"	Roof Finish	11JAN88	25JAN88	11JAN88	25JAN88	0
140	5	5	0		Display Windows	12JAN88	19JAN88	2MAR88	8MAR88	34
130	20	20	0		Finish Plumbing and Heating	18JAN88	12FEB88	9FEB88	8MAR88	16
150	15	15	0		Rough Electrical	26JAN88	15FEB88	26JAN88	15FEB88	0
160	15	15	0		Finish Electrical	16FEB88	8MAR88	16FEB88	8MAR88	0
170	15	15	0		Ceiling	16FEB88	8MAR88	16FEB88	8MAR88	0
180	15	15	0		Paint	9MAR88	29MAR88	9MAR88	29MAR88	0

Figure 8
Schedule After Fourth Iteration

insensitive to rain, no further iterations are required. The final schedule calculated after updating activity 120 is shown in Figure 9. In the final schedule, individual activities have been increased by a cumulative amount of fifteen days, yet the project duration was increased by only eleven project days. The new completion date is calculated as fifteen calendar days beyond the completion date estimated with ideal weather conditions of no rain.

Summary

This chapter presented the methodology for adjusting the durations of rain-sensitive activities. Additionally, the chapter demonstrated software applications that facilitate weather scheduling and methods to assess an activities sensitivity to weather. The method for adjusting the schedule is an iterative process. Specific algorithm steps are performed in each iteration to calculate lost time for rain-sensitive activities based on historical rain data. The method is capable of expansion to consider all weather conditions to which an activity may be sensitive.

The Pennsylvania State University PRIMAVERA PROJECT PLANNER Weather Scheduling Technique

REPORT DATE DDMMMYY RUN NO. XX Variation of Calendar-Day CPM Algorithm START DATE 21SEP87 FIN DATE

SR01 Demo Sched Rep - Sorted by ES, TF DATA DATE DDMMMYY PAGE NO. 1

ACTIVITY NUMBER	ORIG DUR	REM DUR	PCT	CODE	ACTIVITY DESCRIPTION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT
10	11	11	0	0.30"	Demolition (1 WD)	21SEP87	5OCT87	21SEP87	5OCT87	0
20	17	17	0	0.30"	Foundations (2 WD)	6OCT87	29OCT87	6OCT87	29OCT87	0
30	5	5	0	0.30"	Underground Services (0 WD)	6OCT87	13OCT87	13JAN88	20JAN88	65
60	15	15	0		Rough Plumbing and Heating	14OCT87	3NOV87	21JAN88	10FEB88	65
50	36	36	0	0.15"	Exterior Walls (6 WD)	30OCT87	22DEC87	30OCT87	22DEC87	0
40	18	18	0	0.10"	Floor Slab (3 WD)	30OCT87	25NOV87	9DEC87	5JAN88	25
70	10	10	0		Rough Carpentry	27NOV87	10DEC87	21JAN88	3FEB88	35
80	10	10	0		Floor Finish	27NOV87	10DEC87	26FEB88	10MAR88	60
110	20	20	0		Finish Carpentry	11DEC87	11JAN88	4FEB88	3MAR88	35
100	11	11	0	0.15"	Roof Steel (1 WD)	23DEC87	8JAN88	23DEC87	8JAN88	0
90	15	15	0		Interior Walls	23DEC87	14JAN88	6JAN88	27JAN88	8
120	12	12	0	0.10"	Roof Finish (2 WD)	11JAN88	27JAN88	11JAN88	27JAN88	0
140	5	5	0		Display Windows	12JAN88	19JAN88	4MAR88	10MAR88	35
130	20	20	0		Finish Plumbing and Heating	18JAN88	12FEB88	11FEB88	10MAR88	18
150	15	15	0		Rough Electrical	28JAN88	17FEB88	28JAN88	17FEB88	0
160	15	15	0		Finish Electrical	18FEB88	10MAR88	18FEB88	10MAR88	0
170	15	15	0		Ceiling	18FEB88	10MAR88	18FEB88	10MAR88	0
180	15	15	0		Paint	11MAR88	31MAR88	11MAR88	31MAR88	0

Figure 9
Schedule After Fifth and Final Iteration

Chapter IV

EVALUATION OF WEATHER-RELATED TIME EXTENSION REQUESTS

Introduction

The preceding chapter provided a detailed method enabling contractors to incorporate weather delays into a construction schedule. Owners may also use the method in concert with the network adjustment technique developed by Merrill [18] to evaluate weather-related time extension requests. This chapter will present a procedure that uses the adjusted network and the weather scheduling model to evaluate such requests.

Time extension requests for weather are often viewed as a means of compensating for other delays. Owners may try to grant a time extension for weather to avoid the consequences of submittal review delays or withholding site access. Contractors may try requesting time extensions for weather when delayed through their own fault by such actions as project undermanning or poor coordination of trades. Barring these ulterior motives, an owner's evaluation of a weather-related time extension request must consider all delays occurring on the project. Failure to consider all delays during the evaluation could result in granting an excessive extension to the contract completion date. As an example, weather-sensitive activities may have been delayed into an adverse weather period through the contractor's own fault. If predecessor delays are excluded from consideration, the true cause of delay for weather-sensitive activities will not be

identified.

The network adjustment technique by Merrill provides a means of segregating delays that affect the overall completion date of the project from delays that affect only single activities or activity chains [20]. Once the pertinent delays have been identified, weather delays are examined using the weather scheduling technique to differentiate nonexcusable weather delay from excusable, noncompensable weather delay.

Weather Delay Analysis

The combination of the network adjustment technique and the weather scheduling model provides a framework for analyzing weather delays. The network adjustment method systematically removes delays from the as-built schedule. The iterations are continued until a critical path, absent any delays, is identified. At this point, any further delay removal fails to decrease the total project duration. The delays remaining in the adjusted network are considered inconsequential. As delays are removed during the iterations, they are recorded according to delay type, as E,C (excusable/compensable), E,N (excusable/noncompensable), I (nonexcusable), or W (weather).

The completion of delay removals establishes the calendar dates for weather sensitive activities that had weather delays removed. An analysis of project records and weather observations is required to develop sensitivity factors for only those weather sensitive activities with removed delays.

With the calendar dates and sensitivity factors, the extent of a nonexcusable weather delay for an activity is calculated in the same manner as planned lost weather days in chapter three.

When time extension requests for weather are initiated while the project is in progress, the analysis proceeds with a partial as-built network in the same manner as with the complete as-built network. The analysis should be conducted expeditiously after request; otherwise, a contractor may interpret untimely processing of the request as denial. Having reached such an interpretation, the owner will become liable for any acceleration costs the contractor experiences in an effort to meet the current contract completion date. The preparation of the partial as-built network entails reviewing project records such as letters, interoffice memos, job meeting minutes, and schedules. The information obtained during the review is used to construct a schedule that accurately portrays the chronology of the project from the initial activity up to the time of review. The partial as-built schedule also shows the planned sequence of activities from the time of review through project completion. With the partial, as-built schedule, delays are removed iteratively until a critical path absent delays is identified. Removed weather delays are analyzed to distinguish nonexcusable delay from excusable delay.

<u>Network Adjustment Technique Revisions</u>

The network adjustment technique by Merrill [20] pro-

vides a systematic approach for extracting delays from the as-built schedule. Although the approach is orderly and logical, exception is taken with prioritizing delay removal selection according to type in step two. If excusable, compensable delays are given highest priority for removal, the results favor the contractor. Conversely, if nonexcusable delays are prioritized highest, the results favor the owner. To remove this bias from the results, delays will be removed on a last-in, first-out basis, regardless of the type of delay. Delay classifications are still reflected on the network to aid in delay tabulation. The rationale for last-in, first-out delay removal recognizes that delays occurring early in the project along various activity chains consume available slack or float. By removing delays in reverse order of occurrence, the points at which slack is exhausted along activity chains are identified. The underlying principle behind the rationale is that float is not for the exclusive use of either contracting party. Float is available to the party using it first, and it is referred to as "shared float".

A second problem with the network adjustment technique involves weather delays reflected in the network. In the technique demonstration by Merrill, nonexcusable and excusable, noncompensable classifications of weather delays were assumed. The assumptions failed to consider the calendar dates of the affected activities in their final adjusted position. The calendar dates of weather-affected activities

in their final adjusted positions enable the evaluator to define expected weather and lost time for the activity time frames. The expected lost time translates into nonexcusable delay, and the difference between the actual delay and calculated nonexcusable delay translates into excusable, noncompensable delay.

Demonstration of Weather Delay Analysis

To clarify the method for analyzing weather delays, a sample project is presented. The hypothetical network was originally developed by Ponce de Leon [30] and used by Merrill.

Project Review

Figure 10 reflects a 320-day as-built schedule for a 240-day construction contract. The project is assumed to have been constructed in State College, Pennsylvania with a start date of 21 September 1987. Holidays considered in the project schedule are indicated in Table 10, page 40. It is assumed that a review of the project records and weather observations resulted in the following sensitivity factors for rain-delayed activities:

1. Activities 40 and 190 are sensitive to rainfall of 0.10 inches or greater.
2. Activities 140 and 185 are sensitive to rainfall of 0.15 inches or greater.
3. Activity 170 is sensitive to rainfall of 0.30 inches or greater.

This CPM diagram shows identifiable contract activi-

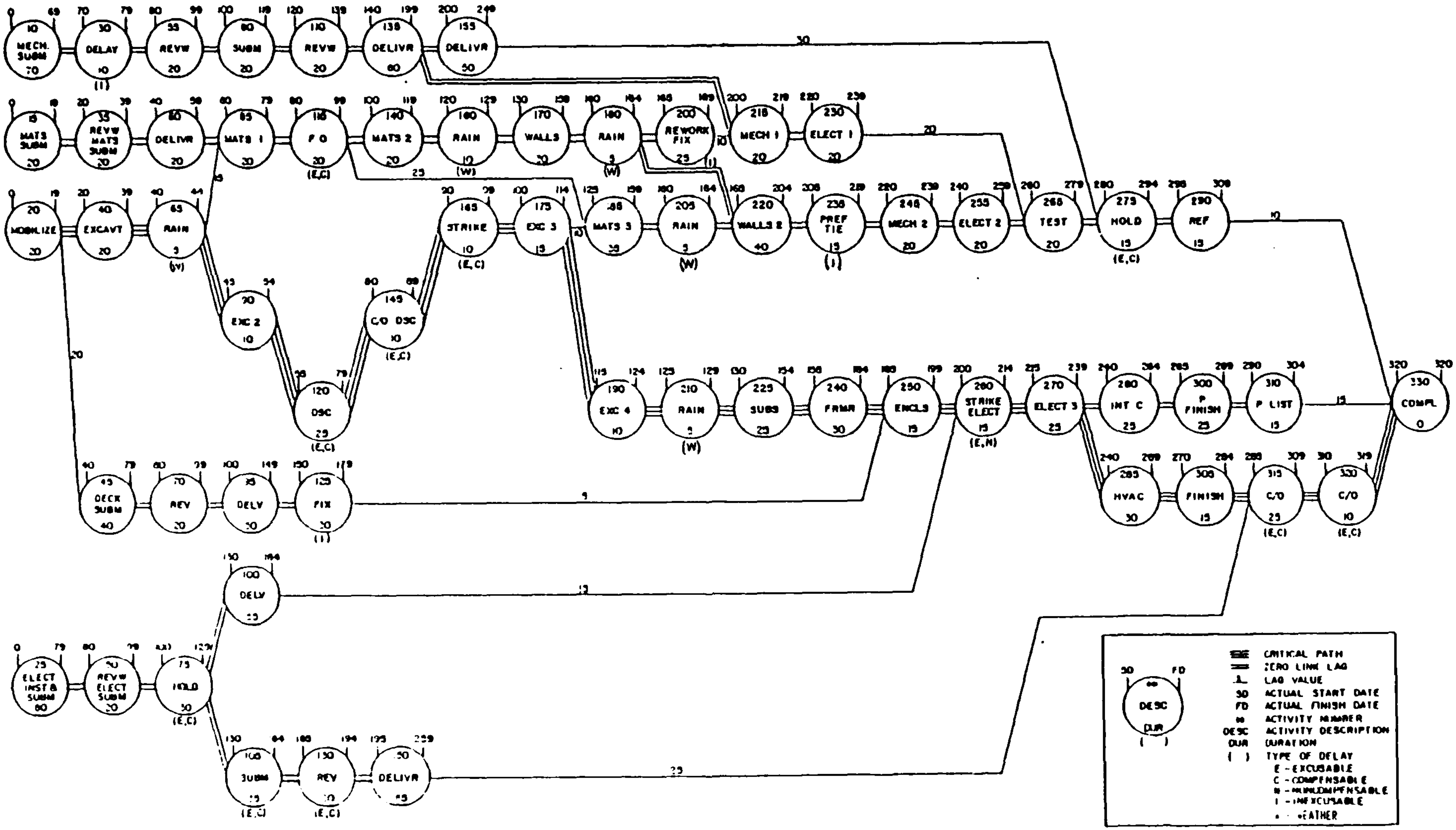


Figure 10
As Built Construction Schedule

ties: as-bid scope of work, excusable delays, suspensions of work, differing site conditions and change orders, nonexcusable delays, and weather delays.

Activities representing the as-built scope of work are shown in their as-built time frames (i.e., from actual starts to actual finishes) except when embedded delays need to be shown. For instance, in the case of rain, finish dates differ from the as-built dates. The intermittent rain delays that occurred during an activity are accumulated and shown on the network after the affected work. These rain activities account for no-work days. The finish dates for the rain delays are the actual finish dates of the rain-impacted activities.

Delay Categories

Identifiable delays in Figure 10 are categorized below. The delay classification that follows is in accordance with the Ponce de Leon example [30].

Activity Number	Type of Delay
	EXCUSABLE - COMPENSABLE
	1. Delays Caused by Owner
75	30-day hold on the processing of instrumentation shop drawings.
115	20 days to process a field order to correct a design defect in the tank base mats and to perform the associated work (change order).
105, 130	65 days for instrumentation resubmittals and review (change order).

165 Ten days of the 20-day Teamsters' strike are considered compensable because two remaining excavation activities would have been completed prior to the strike had it not been for the differing site conditions.

275 15 days of no access to existing facilities for equipment refurbishing.

315, 320 Total of 35 added days of instrumentation work, including tie-ins and testing (change order).

2. Differing Site Conditions

120 25 days due to a differing site condition (poor soil) encountered during excavation.

145 Ten days to correct problems caused by poor soil conditions (change order).

EXCUSABLE - NONCOMPENSABLE

Delays Beyond Contractor and Owner's Control

260 15-day strike activity reflects the impact of an electrician's strike upon electrical work which could have been started on the 200th day.

INEXCUSABLE

Delays For Which Contractor Is Responsible

30 Ten days for late submittal of mechanical

drawings.

125	30 days for refabrication of roof decks which were delivered bowed.
200	25 days spent correcting some defective concrete.
235	15-day restraint on mechanical work due to failure of the subcontractor to add another crew to work on two tanks at same time.

UNCLASSIFIED DELAY TYPE

Weather

65, 160, 180 205, 210	A cumulative total of 30 days were lost due to rain.

Network Adjustment

With delays properly reflected in the as-built network, the adjustment process may commence.

First Iteration. The first step in network adjustment identifies the critical path. The critical path in Figure 11 is identified as the path with zero link lags. Triple line between nodes denote the critical path. By removing delays on a last-in, first-out basis, the initial delay considered for removal is activity 320, the last delay on the critical path. There are no restraints on completely removing activity 320, so the activity is effectively deleted from the network by reducing its duration to zero. Figure 11 depicts the network after the first iteration.

Second Iteration. The completion of the first itera-

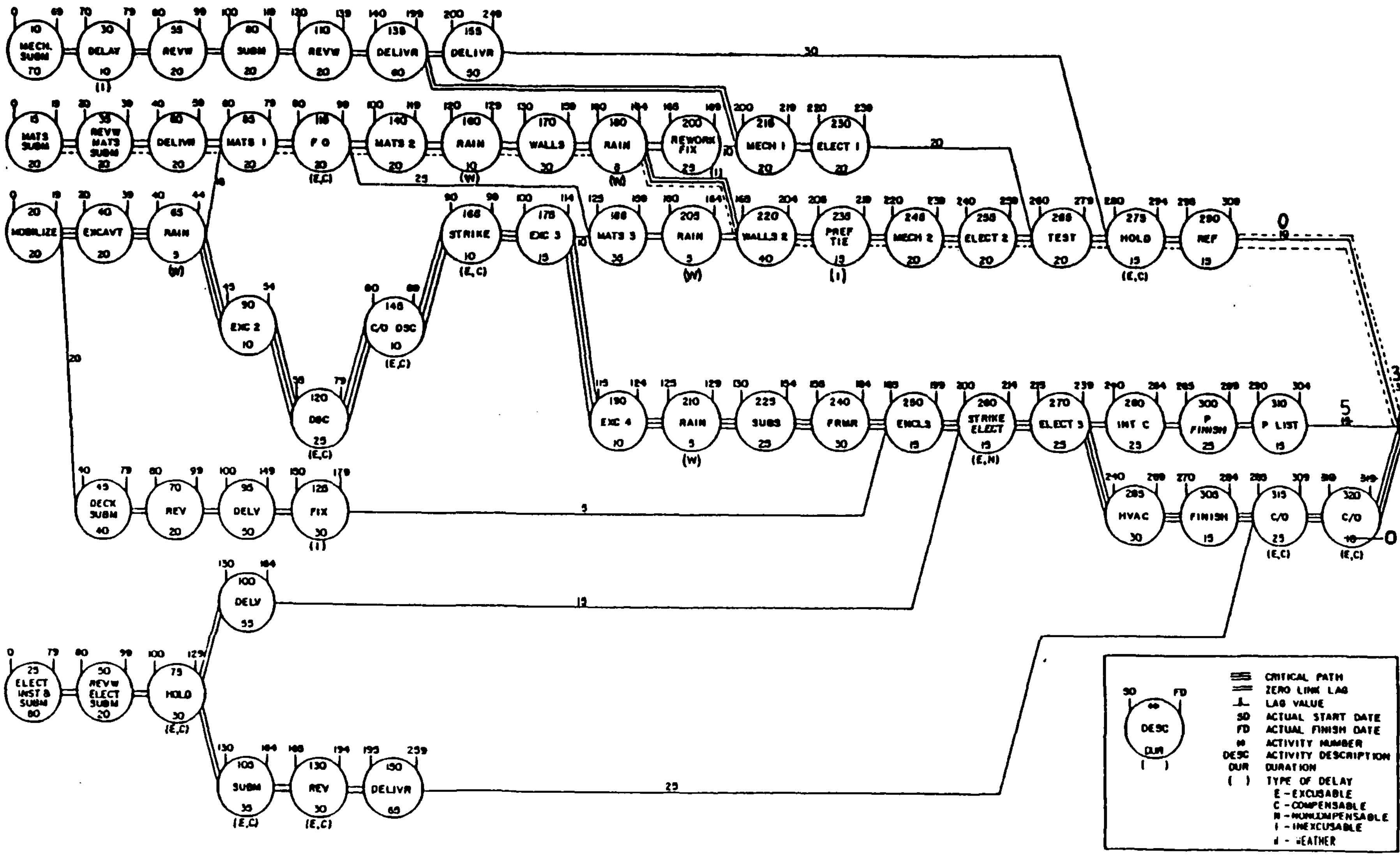


Figure 11
Adjusted Network After First Iteration

tion created a second critical path. Therefore, further delay removal must be accomplished concurrently on the critical paths. In Figure 11, activity 275 on the upper critical path and activity 315 on the lower path are chosen for reduction on the last-in, first-out basis. The reduction is restrained by the link lag between activities 310 and 330, so the maximum reduction equals the value of this link lag. By deducting five days from the delay durations of activities 275 and 315, a third critical path is created. Figure 12 shows the network after the second iteration.

Third Iteration. At this point in the adjustment process, both activity chains from node 270 to node 330 are critical. Therefore, activity 315 may be reduced no further. Working backwards through the critical paths, activities 260 and 275 are considered next. Activity 275 governs for the reduction amount and the maximum reduction for this iteration is ten days. Figure 13 displays the network after delay reduction.

Fourth Iteration. Activities 235 and 260 are considered next. The maximum reduction for this iteration is five days, governed by activity 260. Figure 14 shows the network after delay removal.

Fifth Iteration. The next activities considered for removal are 210 and 235 on the lower and upper paths, respectively. The adjusted network is shown in Figure 15 after removal of five days from delay activities 210 and 235.

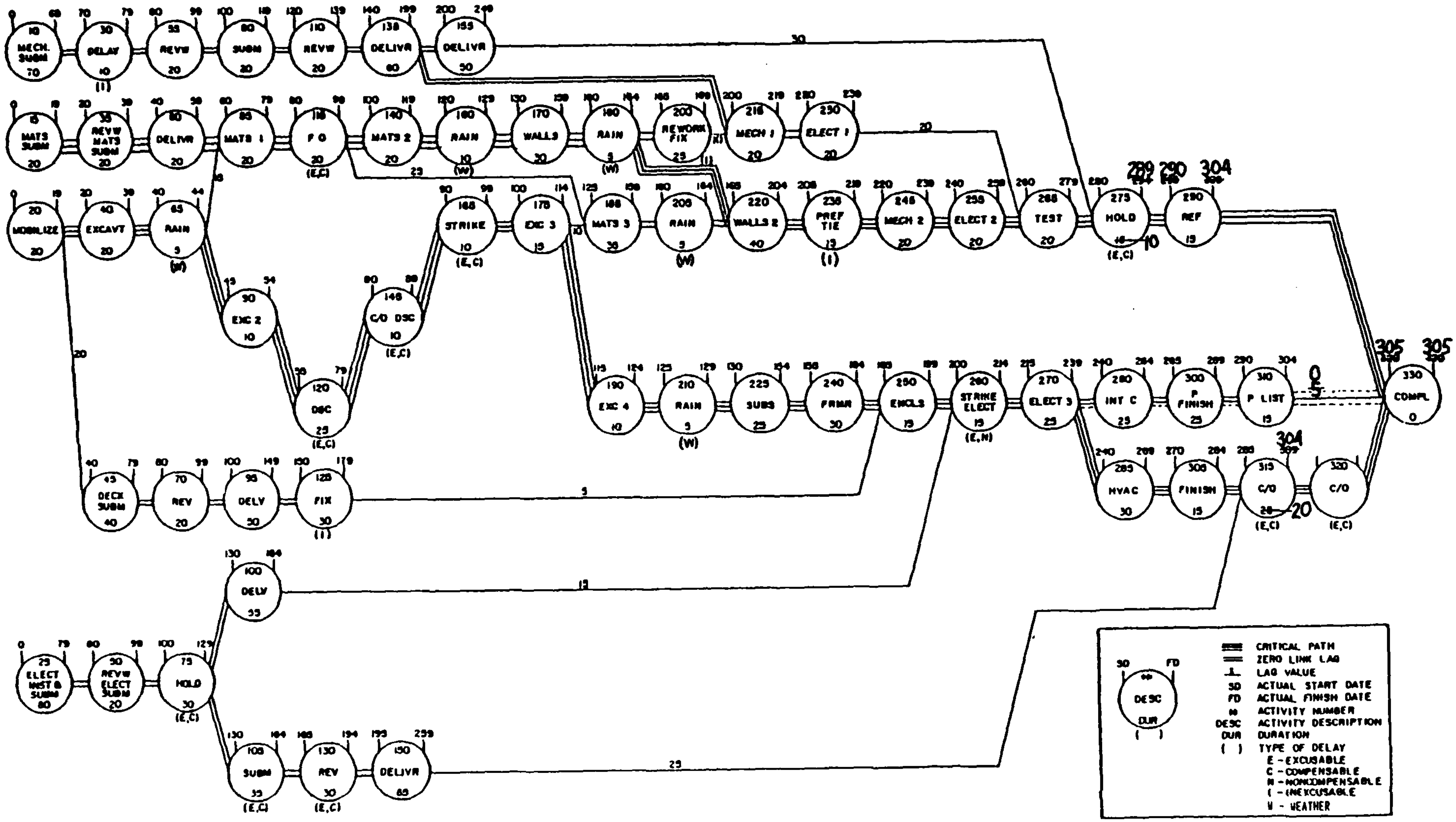


Figure 12
Adjusted Network After Second Iteration

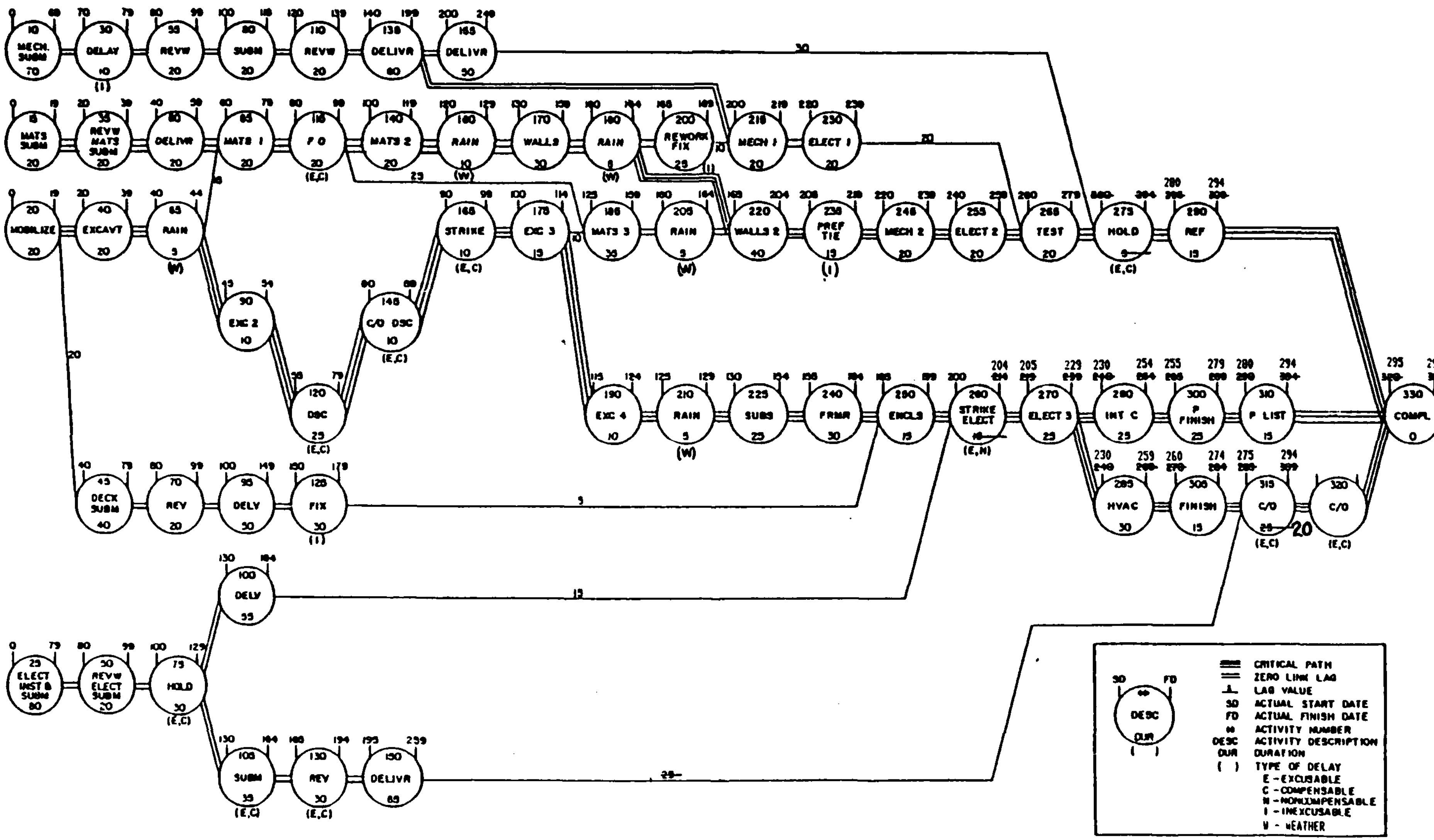


Figure 13
Adjusted Network After Third Iteration

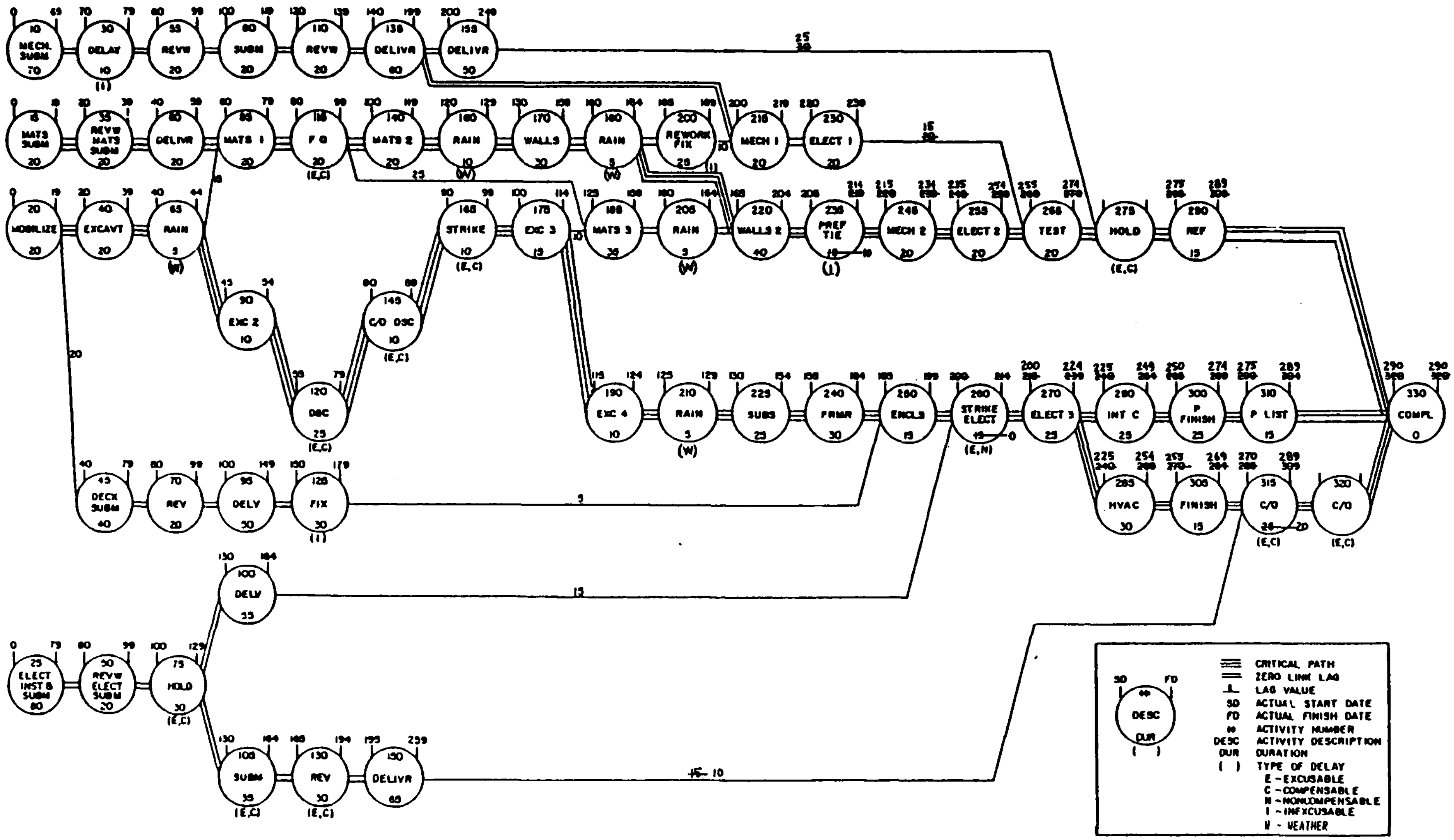


Figure 14
Adjusted Network After Fourth Iteration

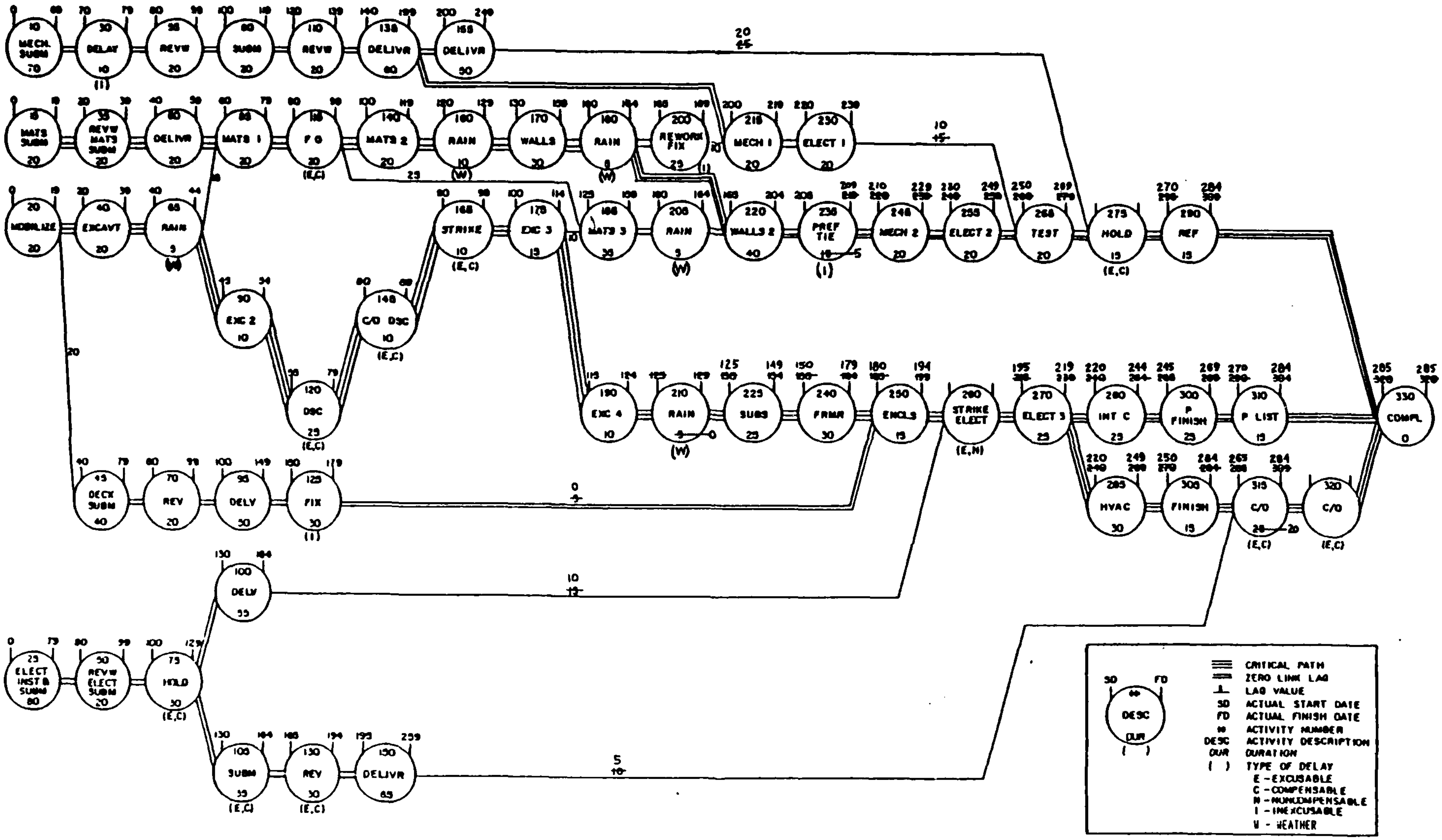


Figure 15
Adjusted Network After Fifth Iteration

Sixth Iteration. Delay activities 165 and 235 are next considered for reduction. The maximum reduction is five days due to activity 235. The adjusted network is shown in Figure 16.

Seventh Iteration. Another critical path was created during he sixth iteration. Accordingly, activities 130, 165 and 180 are considered for reduction on their respective critical paths. The maximum possible reduction is five days for this iteration. Figure 17 shows the network after the seventh iteration.

Eighth Iteration. Two additional critical paths were created during the seventh iteration. Delays considered for concurrent removal along the various critical paths are 30, 75, 145, and 160. The maximum reduction possible is ten days. After removing ten days from the delay activities mentioned above and recalculating the schedule, a critical path absent any delays is identified; therefore, no further iterations are necessary. The adjusted network after the eighth and final iteration is indicated in Figure 18.

Table 20 lists delays removed during each iteration. For concurrent delays removed during an iteration, the effective delay was categorized based on theories of concurrent delay summarized by the Project Management Associates [31].

Analysis of Removed Weather Delays

During the network adjustment process, three rain delays were removed. Table 21 provides information on the

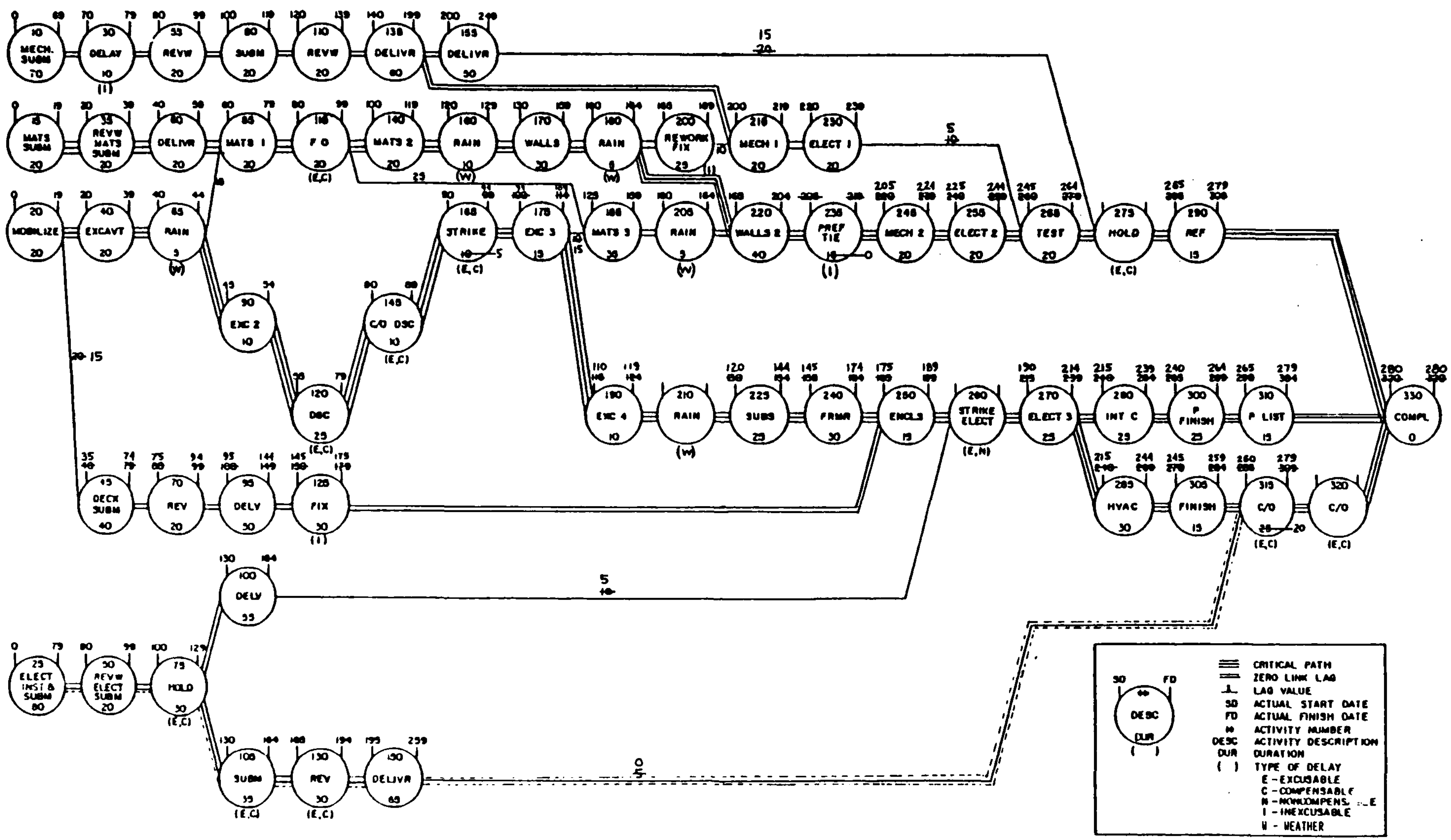


Figure 16
Adjusted Network After Sixth Iteration

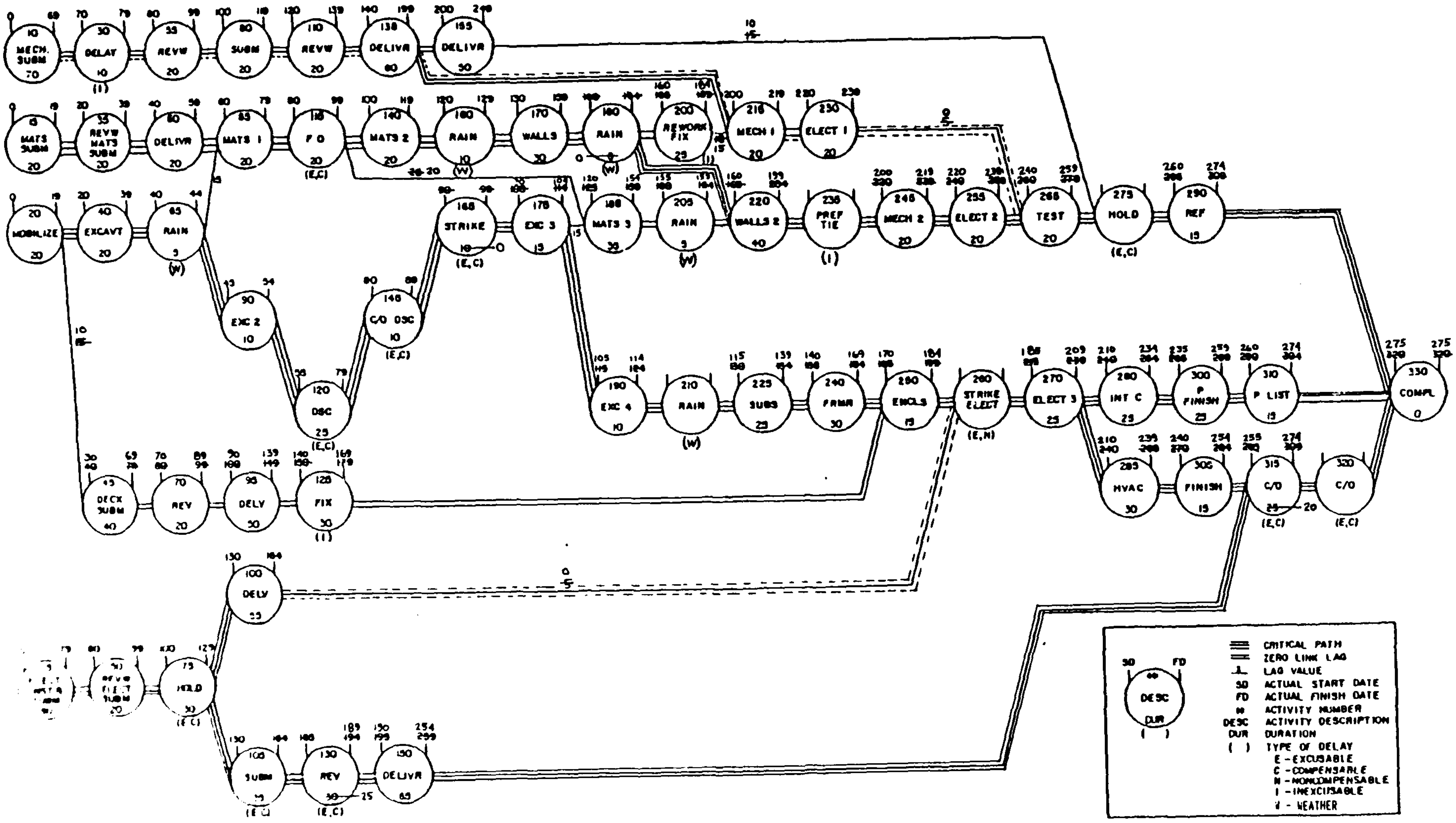


Figure 17
Adjusted Network After Seventh Iteration

AD-A185 024 A MODEL FOR SCHEDULING AND ANALYZING CONSTRUCTION WEATHER DELAYS(U) PENNSYLVANIA STATE UNIV UNIVERSITY PARK DEPT OF CIVIL ENGINEERING F A CANTWELL DEC 87 2/2

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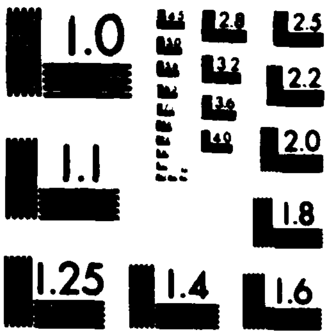
1.0
2.8
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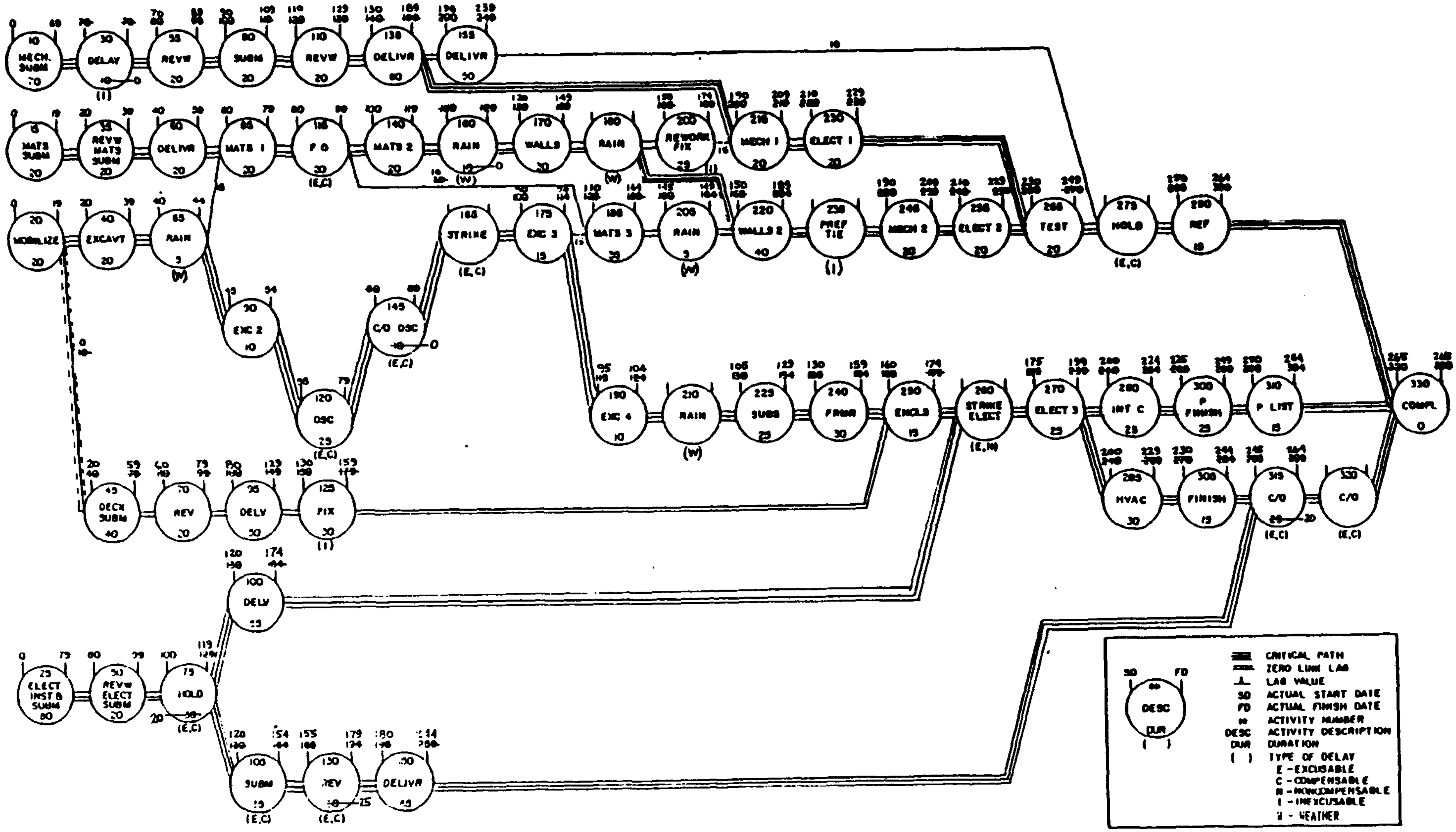

Figure 18
Adjusted Network After Eighth And Final Iteration

Table 20
Summary of Delays Reduced

Iteration	Activity Number(s)	Net Days Reduced	Type of Delays	Effective Category
1	320	10	E,C(C/O)	E,C(C/O)
2	275,320	5	E,C(C/O)	E,C(C/O)
3	260,275	10	E,N + E,C(C/O)	E,C(C/O)
4	235,260	5	I + E,N	E,N
5	210,235	5	W + I	UNKNOWN
6	165,235	5	E,C(DSC) + I	E,C(DSC)
7	130,165,180	5	E,C(C/O) + E,C(DSC) + W	UNKNOWN
8	30,75,145, 160	10	I + E,S(Susp) + E,C(C/O) + W	UNKNOWN

Table 21
Summary of Removed Weather Delays

Delay Activity	Net Days Reduced	Affected Activity	Calendar Dates Before Adjustment	Schedule Dates After Adjustment
160	10	140	100-119 (16Feb88-15Mar88)	100-119 (16Feb88-15Mar88)
180	5	170	130-159 (30Mar88-11May88)	120-19 (16Mar88-27Apr88)
210	5	190	115-12 (9Mar88-2Mar88)	95-104 (9Feb88-23Feb88)

weather delays removed, the extent of reduction, activities affected by these delays, and calendar dates for the affected activities in their original and final positions. For each of these removed rain delays, it is necessary to determine the extent of nonexcusable delay and excusable, noncompensable delay.

The first affected activity considered is number 140. It should be noted that there is no priority for considering affected activities and activity 140 was selected because it

had the lowest activity number. Activity 140 has a rainfall sensitivity factor of 0.15 inches and it occurs in the adjusted network between the dates of 16 February 1988 and 15 March 1988. The extent of nonexcusable delay is found by applying step three from the weather scheduling algorithm and Table 20. For activity 140's calendar dates and sensitivity factor, three lost rain days are calculated. Therefore, because activity 140 can be expected to lose three days in its adjusted position, activity 160 is broken down into three days of nonexcusable delay and two days of excusable, noncompensable delay. Activities 180 and 210 are analyzed in similar fashion.

Upon completion of delay analysis, the summary of removed delays may be completed. Table 22 provides the final summary of delay reductions. Table 23 summarizes delays removed by category, yielding the final recovery for damages:

1. The contractor is entitled to a 27-day time extension for excusable, noncompensable delays. Of these 27 days, three are directly attributable to rain.
2. The contractor should be granted a 26-day time extension for excusable, compensable reasons.
3. 27 days of liquidated damages should be assessed.

Summary

This chapter has presented the methodology for analyzing time extensions requested for weather delays. The meth-

Table 22
Completed Summary of Delays Reduced

Iteration	Activity Number(s)	Net Days Reduced	Type of Delays	Effective Category
1	320	10	E,C(C/O)	E,C(C/O)
2	275,320	5	E,C(C/O)	E,C(C/O)
3	260,275	10	E,N + E,C(C/O)	E,C(C/O)
4	235,260	5	I + E,N	E,N
5a	210,235	2	I(W) + I	I
5b	210,235	3	E,N + I	E,N
6	165,235	5	E,C(DSC) + I	E,C(DSC)
7a	130,165,180	4	E,C(C/O) + E,C(DSC) + I(W)	E,N
7b	130,165,180	1	E,C(C/O) + E,C(DSC) + E,N	E,C(C/O)
8a	30,75,145, 160	3	I + E,S(Susp) + E,C(C/O) + I(W)	E,N
8b	30,75,145, 160	7	I + E,C(Susp) + E,C(C/O) + E,N	E,N

55 days of delay
-2 days removed nonexcusable delay

53 days of reduction

Table 23
Summary of Delays Reduced, By Category

Days Reduced	Type of Delay
27	E,N - Excusable, Noncompensable
26	E,C(C/O) - Excusable, Compensable due to Change Order Work

Actual Duration of Project	320
Excusable, Noncompensable Days Reduced	- 27
Excusable, Compensable (C/O) Days Reduced	- 26
Original Days Planned for Contract Completion	- 240
Number of Days Chargeable for Liquidated Damages	= 27

odology combined aspects of Merrill's network adjustment technique and the weather scheduling model developed in chapter three. The only weather delays considered are those removed during the reduction process. Removed weather delays are not categorized as excusable, noncompensable or nonexcusable until the adjustment process is complete. Once the adjustment process is complete, nonexcusable delay is determined by scheduling weather for affected activities in their final calendar date positions.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

This report presents ~~has presented~~ a deterministic model for incorporating contingency time into a construction schedule for anticipated weather delays. The preliminary steps of organizing historical weather data, establishing weather sensitivity factors for activities, and preparing an "ideal-weather" schedule were detailed prior to introducing the scheduling model. Algorithm steps for incorporating weather delay were explained in detail. To clarify understanding of the algorithm steps, an example was provided that demonstrated the weather scheduling model. A method was also presented for analyzing weather delays effecting ongoing or completed construction contracts. Another sample project was used to demonstrate assessment of weather delay impacts.

Conclusions

Weather is one of the foremost causes of delay on a construction project. Precipitation, temperature, and relative humidity have varying effects on the planned activities that comprise a construction schedule. The effects range from slightly decreased productivity to complete loss of production on a scheduled work day. Contractors must account for the effects of weather when scheduling their construction projects.

The weather scheduling model presented in this report is one of several possible approaches a contractor may use to factor weather into his schedule. In effect, this model

simulates project performance in each of the ten previous years, subject to the daily weather that occurred each year. The cumulative effect on an activity of the simulated weather is averaged to determine expected weather delays in a typical year. Commercially available software eliminates most of the manual effort involved in the model; however, the procedure is not fully automated. The model also provides a framework within which an activities' planned and actual durations of productive time and weather delay time may be recorded and analyzed.

To schedule weather, an understanding of an activity's sensitivity to weather conditions is crucial. An attempt was made to determine rain sensitivity factors for various construction activities. The results were inconclusive due to inconsistent observations. Rainfall that forced some contractors to completely stop work appeared to have minor effects on the productivity of other contractors performing similar or identical operations. Because of the variability of contractor responses to observed weather conditions, sensitivity factors should be developed on an individual contractor basis. An individual contractor's data base of weather sensitivity factors would be analogous to his data base of bid unit prices. The concept of individual contractor sensitivity factors rather than industry-wide factors supports the weather delay analysis method developed in this report.

Historical rainfall recordings used in this report indicate rainfall amounts for 24-hour periods only. The recordings do not indicate if the rain occurred before, during or after normal work hours. Consequently, the model may be overly conservative.

Recommendations for Future Research

The model did not consider soil conditions when excavation sensitivity factors were evaluated. Sensitivity factors for earthmoving activities must include consideration of soil type due to the varying workability of soil types in response to rain. Accordingly, an attempt should be made to verify this model on an actual construction project. The testing could also serve to compare deterministic and stochastic approaches for establishing sensitivity factors. Lastly, studies should be made on how to combine scheduling and database software to fully automate the iterative process for weather scheduling.

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Appendix A

Precipitation Observations over a Ten Year Period in State College, Pennsylvania

Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Jan	87	0.000	0.560	0.400	0.000	0.000	0.000	0.000	0.001
Jan	86	0.001	0.000	0.001	0.001	0.070	0.001	0.001	0.001
Jan	85	0.001	0.190	0.001	0.000	0.130	0.001	0.000	0.020
Jan	84	0.000	0.000	0.001	0.001	0.001	0.010	0.001	0.010
Jan	83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Jan	82	0.480	0.030	0.001	0.830	0.001	0.001	0.080	0.001
Jan	81	0.070	0.070	0.001	0.090	0.010	0.001	0.070	0.001
Jan	80	0.000	0.001	0.001	0.001	0.160	0.001	0.010	0.010
Jan	79	0.040	1.010	0.050	0.001	0.001	0.110	0.030	0.850
Jan	78	0.000	0.030	0.001	0.000	0.000	0.030	0.040	0.750
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Feb	87	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000
Feb	86	0.000	0.140	0.000	0.130	0.570	0.020	0.600	0.250
Feb	85	0.080	0.580	0.150	0.000	0.000	0.060	0.001	0.001
Feb	84	0.001	0.000	0.000	0.080	0.070	0.020	0.000	0.001
Feb	83	0.040	1.220	0.020	0.001	0.000	0.080	0.050	0.001
Feb	82	0.800	0.000	0.490	0.410	0.000	0.000	0.000	0.000
Feb	81	0.000	1.770	0.160	0.000	0.001	0.001	0.001	0.000
Feb	80	0.010	0.001	0.000	0.001	0.001	0.001	0.070	0.001
Feb	79	0.030	0.001	0.001	0.030	0.001	0.000	0.001	0.290
Feb	78	0.001	0.001	0.001	0.000	0.001	0.200	0.400	0.001
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Mar	87	0.410	0.140	0.120	0.001	0.001	0.000	0.000	0.000
Mar	86	0.001	0.000	0.001	0.030	0.040	0.000	0.050	0.000
Mar	85	0.000	0.000	0.000	0.070	0.080	0.001	0.000	0.040
Mar	84	0.001	0.001	0.001	0.001	0.050	0.310	0.001	0.000
Mar	83	0.000	0.000	0.000	0.000	0.000	0.000	0.230	0.001
Mar	82	0.000	0.001	0.290	0.000	0.260	0.000	0.370	0.370
Mar	81	0.030	0.000	0.001	0.001	0.120	0.180	0.001	0.001
Mar	80	0.000	0.010	0.000	0.000	0.060	0.060	0.001	0.330
Mar	79	0.000	0.040	0.000	0.020	1.390	0.820	0.000	0.000
Mar	78	0.010	0.020	0.120	0.060	0.001	0.001	0.000	0.000
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Apr	87	0.470	0.001	0.060	0.840	0.540	0.410	0.510	0.110
Apr	86	0.000	0.001	0.000	0.001	0.010	0.260	0.230	0.010
Apr	83	0.020	0.000	0.670	0.070	0.001	0.001	0.210	0.330
Apr	82	0.150	0.001	0.350	0.610	0.030	0.440	0.120	0.000
Apr	81	0.000	0.160	0.000	0.000	0.030	0.130	0.001	0.000
Apr	80	0.240	0.000	0.020	0.290	0.010	0.000	0.000	0.001
Apr	79	0.070	0.500	0.080	0.000	0.450	0.060	0.001	0.001
Apr	78	0.001	0.001	0.060	0.240	0.470	0.000	0.300	0.000
Apr	77	0.001	0.010	1.800	0.000	0.420	0.160	0.100	0.080
Apr	76	0.690	0.090	0.010	0.010	0.040	0.000	0.010	0.000

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Jan	87	0.001	0.170	0.050	0.001	0.001	0.000	0.001	0.001
Jan	86	0.000	0.000	0.001	0.000	0.001	0.010	0.030	0.000
Jan	85	0.001	0.000	0.180	0.060	0.001	0.000	0.000	0.001
Jan	84	0.060	0.010	0.310	0.000	0.001	0.060	0.001	0.001
Jan	83	0.000	0.070	0.280	0.010	0.001	0.001	0.220	0.260
Jan	82	0.001	0.060	0.001	0.001	0.030	0.180	0.001	0.050
Jan	81	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.050
Jan	80	0.000	0.060	0.001	0.120	0.000	0.130	0.640	0.000
Jan	79	0.020	0.001	0.001	0.030	0.060	0.280	0.120	0.000
Jan	78	1.250	0.100	0.001	0.000	0.060	0.750	0.150	0.001
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Feb	87	0.001	0.000	0.000	0.040	0.210	0.000	0.001	0.000
Feb	86	0.001	0.001	0.310	0.040	0.020	0.001	0.030	0.000
Feb	85	0.001	0.001	0.001	0.230	1.220	0.010	0.030	0.001
Feb	84	0.000	0.000	0.050	0.150	0.001	0.660	2.380	0.140
Feb	83	0.000	0.030	0.800	0.000	0.000	0.000	0.000	0.000
Feb	82	0.220	0.070	0.000	0.001	0.050	0.020	0.000	0.001
Feb	81	0.260	0.000	0.630	0.290	0.000	0.000	0.000	0.000
Feb	80	0.001	0.001	0.000	0.050	0.001	0.000	0.001	0.260
Feb	79	0.010	0.000	0.001	0.000	0.230	0.001	0.100	0.230
Feb	78	0.001	0.000	0.000	0.001	0.001	0.310	0.000	0.010
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Mar	87	0.000	0.000	0.000	0.000	0.000	0.000	0.270	0.000
Mar	86	0.000	0.001	0.230	0.000	0.280	0.270	1.750	0.001
Mar	85	0.001	0.000	0.000	0.590	0.010	0.001	0.020	0.000
Mar	84	0.320	0.000	0.001	0.001	0.210	0.220	0.000	0.000
Mar	83	0.040	0.390	0.190	0.001	0.000	0.000	0.001	0.000
Mar	82	0.110	0.100	0.001	0.180	0.160	0.000	0.000	0.001
Mar	81	0.001	0.001	0.030	0.020	0.000	0.001	0.000	0.050
Mar	80	0.430	0.001	0.040	0.001	0.010	0.610	0.001	0.000
Mar	79	0.000	0.010	0.140	0.001	0.001	0.050	0.140	0.001
Mar	78	0.001	0.000	0.000	0.030	0.001	0.030	0.410	0.050
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Apr	87	0.000	0.000	0.000	0.060	0.310	0.050	0.000	0.010
Apr	86	0.000	0.001	0.010	0.070	0.001	0.001	0.020	0.610
Apr	83	0.410	0.730	0.040	0.090	0.001	0.000	0.900	0.230
Apr	82	0.060	0.440	0.001	0.001	0.001	0.010	0.000	0.000
Apr	81	0.001	0.100	0.001	0.700	0.290	0.330	0.250	0.000
Apr	80	1.710	0.230	0.001	0.000	0.030	0.560	0.600	0.010
Apr	79	0.220	0.350	0.000	0.010	0.190	0.180	0.080	0.010
Apr	78	0.000	0.000	0.001	0.140	0.000	0.000	0.000	0.001
Apr	77	0.001	0.000	0.000	0.000	0.000	0.010	0.000	0.000
Apr	76	0.000	0.000	0.001	0.010	0.000	0.000	0.000	0.000

Appendix A (continued)

Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Jan	87	0.000	0.000	0.100	0.800	0.800	0.000	0.000	0.000
Jan	86	0.000	0.001	0.020	1.080	0.450	0.000	0.001	0.000
Jan	85	0.120	0.010	0.140	0.030	0.001	0.001	0.001	0.001
Jan	84	0.070	0.001	0.180	0.000	0.001	0.001	0.000	0.280
Jan	83	0.001	0.001	0.001	0.000	0.000	0.000	0.130	0.200
Jan	82	0.070	0.001	0.000	0.030	0.120	0.001	1.360	0.290
Jan	81	0.070	0.001	0.001	0.000	0.000	0.000	0.001	0.010
Jan	80	0.000	0.001	0.000	0.000	0.001	0.001	0.020	0.001
Jan	79	0.000	0.240	0.001	0.000	1.080	0.001	0.001	0.120
Jan	78	0.110	1.120	0.000	0.510	0.680	0.020	0.000	0.000
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Feb	87	0.000	0.000	0.000	0.000	0.000	0.000	0.380	0.001
Feb	86	0.250	0.030	0.060	0.380	0.010	0.400	0.250	0.000
Feb	85	0.000	0.001	0.000	0.000	0.000	0.001	0.001	0.000
Feb	84	0.001	0.190	0.020	0.370	0.001	0.040	0.000	0.001
Feb	83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feb	82	0.070	0.900	0.300	0.060	0.100	0.020	0.000	0.060
Feb	81	0.010	0.001	0.000	0.760	0.410	0.030	0.150	1.260
Feb	80	0.030	0.001	0.000	0.000	0.001	0.360	0.100	0.030
Feb	79	0.001	0.000	0.480	0.000	0.000	0.130	0.030	0.230
Feb	78	0.020	0.001	0.120	0.000	0.000	0.000	0.001	0.001
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Mar	87	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.000
Mar	86	0.001	0.000	0.050	0.150	0.000	0.000	0.000	0.000
Mar	85	0.000	0.001	0.000	0.040	0.000	0.000	0.590	0.790
Mar	84	0.010	0.000	0.020	0.000	0.010	0.260	0.010	0.020
Mar	83	0.000	0.001	0.480	0.280	0.350	0.870	0.001	0.000
Mar	82	0.420	0.000	0.000	0.001	0.430	0.001	0.001	0.000
Mar	81	0.000	0.030	0.001	0.001	0.200	0.000	0.000	0.000
Mar	80	0.000	0.380	0.000	0.000	0.250	0.760	0.010	0.000
Mar	79	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.260
Mar	78	0.220	0.001	0.001	0.000	0.001	0.220	0.001	0.001
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Apr	87	0.170	0.050	0.020	0.020	0.030	0.000	0.000	0.490
Apr	86	0.900	0.360	0.000	0.001	0.190	0.040	0.160	0.000
Apr	83	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.430
Apr	82	0.001	0.150	0.000	0.000	0.010	0.000	0.000	0.000
Apr	81	0.070	0.030	0.000	0.001	0.000	0.000	0.060	0.200
Apr	80	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Apr	79	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Apr	78	0.000	0.000	0.300	0.570	0.070	0.040	0.000	0.040
Apr	77	0.000	0.000	0.000	0.180	0.040	0.000	0.000	0.570
Apr	76	0.000	0.000	0.000	0.000	0.000	0.350	0.001	0.020

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty	Thone
Jan	87	0.000	0.000	0.000	0.000	0.001	0.150	0.080
Jan	86	0.001	0.470	0.050	0.001	0.001	0.180	0.001
Jan	85	0.020	0.120	0.001	0.001	0.001	0.001	0.100
Jan	84	0.070	0.000	0.000	0.000	0.020	0.090	0.210
Jan	83	0.001	0.001	0.001	0.001	0.001	0.001	0.180
Jan	82	0.001	0.001	0.001	0.000	0.000	0.001	0.110
Jan	81	0.000	0.000	0.000	0.000	0.020	0.001	0.000
Jan	80	0.060	0.020	0.000	0.001	0.001	0.001	0.010
Jan	79	1.060	0.050	0.001	0.010	0.010	0.001	0.001
Jan	78	0.280	1.370	0.030	0.010	0.010	0.020	0.001

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin
Feb	87	0.000	0.000	0.000	0.001	
Feb	86	0.001	0.000	0.040	0.020	
Feb	85	0.030	0.000	0.010	0.001	
Feb	84	0.000	0.060	0.000	0.200	0.570
Feb	83	0.130	0.001	0.000	0.000	
Feb	82	0.110	0.000	0.000	0.000	
Feb	81	0.020	0.000	0.000	0.000	
Feb	80	0.000	0.010	0.001	0.040	0.001
Feb	79	0.200	1.110	0.270	0.001	
Feb	78	0.010	0.040	0.010	0.000	

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty	Thone
Mar	87	0.000	0.260	0.000	0.001	0.001	0.001	1.060
Mar	86	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Mar	85	0.430	0.000	0.000	0.040	1.060	0.170	0.350
Mar	84	0.001	0.010	0.000	0.140	1.600	0.630	0.030
Mar	83	0.000	0.000	0.001	1.030	0.070	0.000	0.000
Mar	82	0.000	0.590	0.030	0.001	0.000	0.000	0.020
Mar	81	0.000	0.000	0.080	0.000	0.000	0.020	0.190
Mar	80	0.090	0.001	0.000	0.000	0.480	0.040	0.520
Mar	79	0.900	0.060	0.001	0.001	0.020	0.010	0.000
Mar	78	0.001	0.530	0.310	0.000	0.001	0.000	0.000

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty
Apr	87	0.140	0.000	0.000	0.300	0.030	0.001
Apr	86	0.000	0.000	0.000	0.000	0.000	0.000
Apr	83	0.880	0.020	0.001	0.000	0.000	0.990
Apr	82	0.000	0.000	0.040	0.040	0.000	0.000
Apr	81	0.030	0.000	0.001	0.000	0.600	0.090
Apr	80	0.001	0.000	0.430	0.170	0.590	0.020
Apr	79	0.001	0.001	0.450	0.110	0.001	0.000
Apr	78	0.001	0.000	0.000	0.000	0.000	0.001
Apr	77	0.250	0.001	0.001	0.000	0.060	0.000
Apr	76	0.030	0.370	0.010	0.000	0.000	0.000

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
May	87	0.000	0.001	0.110	1.050	0.110	0.000	0.000	0.000
May	84	0.010	0.000	0.000	0.570	0.020	0.001	0.000	0.040
May	83	0.750	0.480	0.350	0.130	0.001	0.000	0.000	0.050
May	82	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.650
May	81	0.000	0.080	0.000	0.000	0.000	0.040	0.070	0.000
May	80	0.040	0.000	0.110	0.001	0.000	0.000	0.001	0.001
May	79	0.001	0.000	0.001	0.280	0.010	0.000	0.000	0.000
May	78	0.000	0.000	0.000	0.000	0.590	0.080	0.001	0.001
May	77	0.000	0.001	0.150	0.010	0.180	0.070	0.300	0.000
May	76	0.000	0.210	0.020	0.010	0.001	0.000	0.070	0.001
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Jun	86	0.000	0.020	0.000	0.000	0.010	0.530	0.140	0.220
Jun	85	0.380	0.000	0.000	0.001	0.510	0.001	0.000	0.010
Jun	84	0.000	0.000	0.320	0.000	0.000	0.000	0.070	0.000
Jun	83	0.110	0.050	0.000	0.650	0.010	0.000	0.390	0.000
Jun	82	0.000	0.350	0.000	0.540	0.610	1.700	0.290	0.010
Jun	81	0.001	0.250	0.020	1.130	0.001	0.001	0.000	0.000
Jun	80	0.060	0.110	0.020	0.100	0.000	0.001	0.001	0.620
Jun	79	0.001	0.060	0.000	0.010	0.000	0.000	0.020	0.001
Jun	78	0.001	0.000	0.590	0.140	0.000	0.000	0.001	0.470
Jun	77	0.140	0.001	0.001	0.000	0.000	0.090	1.040	0.000
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Jul	86	0.001	0.780	0.001	0.000	0.000	0.000	0.000	0.000
Jul	85	0.000	0.001	0.060	0.050	0.001	0.320	0.140	0.020
Jul	84	1.120	0.860	0.030	0.000	0.180	0.090	0.350	0.000
Jul	83	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Jul	82	0.010	0.000	0.010	0.720	0.000	0.000	0.000	0.000
Jul	81	0.001	0.770	0.330	0.020	0.150	0.060	0.000	0.000
Jul	80	0.001	0.000	0.001	0.190	0.000	0.050	0.000	0.520
Jul	79	0.300	0.460	0.001	0.300	0.280	0.000	0.000	0.000
Jul	78	0.000	0.000	0.800	0.080	0.001	0.001	0.000	0.000
Jul	77	0.030	0.000	0.000	0.001	0.190	0.000	0.460	1.490
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Aug	86	0.000	0.000	0.130	0.000	0.000	0.000	0.130	0.030
Aug	85	0.080	0.000	0.000	0.000	0.000	0.000	0.001	0.500
Aug	84	0.000	0.010	0.220	0.030	0.760	0.020	0.190	0.090
Aug	83	0.000	0.390	0.000	0.000	0.001	0.010	0.000	0.001
Aug	82	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.010
Aug	81	0.000	0.000	0.000	0.660	0.001	0.000	0.000	0.140
Aug	80	0.010	0.000	0.620	0.370	0.000	0.100	0.090	0.000
Aug	79	0.060	0.010	0.001	0.000	0.000	0.000	0.010	0.750
Aug	78	0.100	0.000	0.000	0.930	0.000	0.290	0.030	0.680
Aug	77	0.001	0.000	0.000	0.000	0.000	0.000	0.630	0.510

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
May	87	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
May	84	0.140	0.020	0.050	0.260	0.030	0.260	0.001	0.010
May	83	0.150	0.001	0.000	0.000	0.000	0.000	0.000	0.160
May	82	0.460	0.000	0.000	0.000	0.080	0.000	0.000	0.000
May	81	0.000	0.000	0.200	0.590	0.020	0.000	0.001	0.160
May	80	0.000	0.000	0.180	0.620	1.050	0.080	0.001	0.000
May	79	0.000	0.000	0.330	0.001	0.070	0.001	0.000	0.110
May	78	0.400	0.020	0.000	0.000	0.040	1.420	0.930	0.480
May	77	0.030	0.001	0.000	0.000	0.001	0.001	0.000	0.000
May	76	0.000	0.000	0.000	0.020	0.000	0.000	0.050	0.350
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Jun	86	0.001	0.000	0.130	0.990	0.190	0.000	0.460	0.000
Jun	85	0.390	0.200	0.000	0.210	0.001	0.001	0.010	0.370
Jun	84	0.000	0.000	0.000	0.000	0.000	0.460	0.001	0.000
Jun	83	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Jun	82	0.000	0.020	1.070	0.000	0.640	0.250	0.000	0.000
Jun	81	0.660	0.030	0.310	0.000	0.000	0.670	1.040	0.001
Jun	80	0.000	0.580	0.001	0.000	0.000	0.000	0.000	0.050
Jun	79	1.310	0.001	0.050	0.001	0.000	0.000	0.000	0.000
Jun	78	0.060	0.001	0.000	0.000	0.300	0.001	0.000	0.000
Jun	77	0.220	0.380	0.000	0.000	0.030	0.001	0.010	0.000
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Jul	86	0.390	0.220	0.001	0.330	0.360	0.001	0.000	0.000
Jul	85	0.450	0.001	0.340	0.001	0.080	0.000	0.390	0.030
Jul	84	0.000	0.000	0.150	0.650	0.000	0.000	0.000	0.020
Jul	83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	82	0.001	0.000	0.000	0.150	0.000	0.000	0.000	0.000
Jul	81	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
Jul	80	0.020	0.000	0.000	0.001	0.000	0.000	0.000	0.140
Jul	79	0.000	0.160	0.010	0.000	0.010	0.000	0.001	0.000
Jul	78	0.000	0.001	0.010	0.000	0.000	0.030	0.250	0.000
Jul	77	0.000	0.030	0.100	0.150	0.260	0.000	0.000	0.000
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Aug	86	0.010	0.000	0.100	0.000	0.000	0.000	0.000	0.001
Aug	85	0.001	0.000	0.001	0.001	0.000	0.070	0.000	0.060
Aug	84	0.260	0.730	0.010	1.320	0.370	0.190	0.250	0.000
Aug	83	0.000	0.000	0.000	0.630	0.001	0.000	0.000	0.000
Aug	82	0.190	1.890	0.070	0.040	0.000	0.000	0.000	0.000
Aug	81	0.140	0.000	0.000	0.070	0.000	0.000	0.000	0.030
Aug	80	0.100	0.000	0.340	0.990	0.001	0.001	0.520	0.000
Aug	79	0.000	0.000	0.820	1.200	0.190	0.000	0.001	0.001
Aug	78	0.000	0.070	0.000	0.040	0.001	0.001	0.000	0.000
Aug	77	0.060	0.180	0.210	0.001	0.000	0.000	0.210	0.000

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
May	87	0.000	0.000	0.480	0.920	0.000	0.000	0.000	0.000
May	84	0.000	0.000	0.730	0.001	0.400	0.010	0.070	0.160
May	83	0.040	0.000	0.000	0.530	0.000	0.370	1.150	0.040
May	82	0.000	0.060	0.000	0.070	0.150	0.040	0.950	0.300
May	81	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	80	0.000	0.190	0.010	0.001	0.230	0.001	0.000	0.010
May	79	0.000	0.000	0.020	0.001	0.030	0.070	0.260	2.020
May	78	0.690	0.250	0.000	0.000	0.030	0.000	0.000	1.260
May	77	0.000	0.001	0.030	0.000	0.000	0.000	0.000	0.000
May	76	0.510	0.230	0.210	0.040	0.020	0.000	0.000	0.000
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Jun	86	0.490	0.000	0.000	0.160	0.000	0.000	0.070	0.010
Jun	85	0.640	0.220	0.001	0.000	0.210	0.000	0.180	0.000
Jun	84	0.001	2.590	0.680	0.000	0.000	0.000	0.000	0.010
Jun	83	0.030	0.070	0.050	0.130	1.150	0.010	0.000	0.000
Jun	82	0.470	0.010	0.000	0.040	0.090	0.000	0.220	0.000
Jun	81	0.150	0.000	0.000	0.270	0.010	0.450	0.300	0.000
Jun	80	0.000	0.000	0.000	0.060	0.001	0.000	0.000	0.000
Jun	79	0.001	0.001	0.000	0.000	0.000	0.030	0.001	0.000
Jun	78	0.190	0.120	0.001	0.001	0.000	0.780	0.000	0.000
Jun	77	0.000	0.470	0.001	0.000	0.040	0.000	0.000	0.000
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Jul	86	0.920	0.050	0.130	0.410	0.150	0.000	0.000	0.000
Jul	85	0.000	0.000	0.000	0.010	0.000	0.130	0.000	0.000
Jul	84	0.000	0.410	0.010	0.000	0.000	0.000	0.000	0.000
Jul	83	0.000	0.350	0.000	0.020	0.020	0.130	0.000	1.530
Jul	82	0.000	0.000	0.040	1.600	0.001	0.000	0.000	0.000
Jul	81	0.001	0.000	0.000	0.500	1.460	0.010	0.000	0.000
Jul	80	0.960	0.000	0.000	0.000	0.000	0.040	0.190	0.000
Jul	79	0.010	0.000	0.000	0.000	0.000	0.000	0.001	0.490
Jul	78	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.160
Jul	77	0.120	0.350	0.000	0.740	0.000	0.290	0.000	0.000
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Aug	86	0.030	0.090	0.000	0.000	0.080	0.150	0.000	0.860
Aug	85	0.150	0.000	0.000	0.150	0.000	0.000	0.000	0.000
Aug	84	0.000	0.000	1.310	0.000	0.000	0.000	0.000	0.000
Aug	83	0.000	0.460	0.130	0.000	0.000	0.040	0.000	0.000
Aug	82	0.000	0.230	0.000	0.000	0.100	0.030	0.001	0.090
Aug	81	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	80	0.010	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Aug	79	0.000	0.000	0.400	0.000	0.180	0.040	0.000	0.040
Aug	78	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Aug	77	0.620	0.100	0.000	0.001	0.000	0.080	0.000	0.020

Appendix A (continued)

Precipitation Observations over a Ten Year Period in State College, Pennsylvania

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty	Thone
May	87	0.000	0.000	0.000	0.000	0.000	0.000	0.000
May	84	0.000	0.000	0.001	0.590	0.610	0.010	0.000
May	83	0.000	0.010	0.000	0.000	0.270	0.090	0.070
May	82	0.140	0.001	0.001	0.040	1.190	0.001	0.170
May	81	0.000	0.050	0.100	0.001	0.430	0.001	0.330
May	80	0.001	0.000	0.000	0.000	0.000	0.080	0.030
May	79	0.260	0.200	0.010	0.190	0.050	0.070	0.040
May	78	0.190	0.000	0.000	0.000	0.000	0.000	0.001
May	77	0.770	0.000	0.000	0.000	0.000	0.000	0.000
May	76	0.000	1.600	0.010	0.000	0.001	0.250	0.550

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty
Jun	86	0.000	0.000	0.000	0.001	0.020	0.000
Jun	85	0.000	0.000	0.000	0.000	0.120	0.010
Jun	84	0.540	0.030	0.000	0.020	0.000	0.001
Jun	83	0.000	0.000	0.000	0.680	1.480	0.000
Jun	82	0.000	0.000	0.001	0.210	0.250	0.060
Jun	81	0.070	0.520	0.000	0.000	0.000	0.000
Jun	80	0.000	0.000	0.000	0.000	0.010	0.140
Jun	79	0.000	0.000	0.000	0.000	0.060	0.730
Jun	78	0.000	0.001	0.190	0.230	0.000	0.110
Jun	77	0.000	2.020	0.000	0.000	0.610	0.001

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty	Thone
Jul	86	0.000	0.020	0.090	0.000	0.010	0.000	0.290
Jul	85	0.000	0.270	0.390	0.000	0.000	0.000	0.210
Jul	84	0.000	0.000	0.570	0.000	0.000	0.000	0.000
Jul	83	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Jul	82	0.000	0.000	0.010	0.970	0.040	0.000	0.000
Jul	81	0.020	0.001	0.820	0.001	0.310	0.000	0.000
Jul	80	0.000	0.000	0.000	0.000	0.620	0.060	0.000
Jul	79	0.030	0.140	0.001	0.000	0.420	0.580	0.001
Jul	78	0.001	0.001	0.000	0.490	0.000	0.110	0.550
Jul	77	0.410	1.320	0.000	0.000	0.000	0.020	0.001

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty	Thone
Aug	86	0.000	0.000	0.010	0.010	0.000	0.000	0.000
Aug	85	0.500	0.230	0.040	0.000	0.000	0.000	0.200
Aug	84	0.000	0.000	0.000	0.000	0.010	0.000	0.360
Aug	83	0.000	0.000	0.000	0.130	0.010	0.010	0.460
Aug	82	0.620	0.001	0.001	0.001	0.000	0.001	0.000
Aug	81	0.001	0.000	0.000	0.000	0.070	0.010	0.120
Aug	80	0.000	0.000	0.000	0.000	0.000	0.000	0.050
Aug	79	0.200	0.000	0.860	0.000	0.001	0.440	0.000
Aug	78	0.000	0.000	0.000	0.000	0.200	0.001	0.450
Aug	77	0.001	0.000	0.030	0.001	0.000	0.000	0.001

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Sep	86	0.000	0.000	0.000	0.010	0.050	0.110	0.000	0.001
Sep	85	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.001
Sep	83	0.030	0.000	0.000	0.000	0.001	0.010	0.000	0.000
Sep	82	0.030	0.180	0.620	0.000	0.000	0.000	0.000	0.040
Sep	81	0.060	0.520	0.250	0.590	0.300	0.001	0.090	0.060
Sep	80	0.000	0.010	0.190	0.000	0.050	0.000	0.000	0.000
Sep	79	0.000	0.000	1.630	0.000	0.000	1.740	0.010	0.000
Sep	78	0.330	0.000	0.000	0.170	0.000	0.000	0.000	0.001
Sep	77	0.000	0.000	0.010	0.000	0.000	0.001	0.001	0.000
Sep	76	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Oct	86	0.650	0.160	0.100	0.730	0.130	0.010	0.001	0.000
Oct	85	0.000	0.580	0.020	0.001	0.030	0.010	0.000	0.000
Oct	84	0.670	0.110	0.000	0.860	0.000	0.000	0.000	0.001
Oct	83	0.440	0.010	0.000	0.000	0.001	0.090	0.000	0.000
Oct	82	0.000	0.000	0.000	0.000	0.020	0.020	0.000	0.060
Oct	81	0.130	0.080	0.040	0.000	0.001	0.200	0.170	0.010
Oct	80	0.000	0.000	0.020	0.550	0.000	0.000	0.070	0.000
Oct	79	0.001	0.010	1.510	0.050	0.080	1.300	0.070	0.090
Oct	78	0.000	0.001	0.000	0.370	0.001	0.010	0.001	0.001
Oct	77	0.001	0.520	0.001	0.000	0.000	0.190	0.020	0.001
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Nov	86	0.000	0.000	0.000	0.100	0.100	0.410	0.000	0.440
Nov	84	0.000	0.010	0.000	0.000	0.680	0.010	0.010	0.000
Nov	83	0.000	0.000	0.190	0.070	0.100	0.070	0.001	0.001
Nov	82	0.001	0.000	0.000	0.240	0.720	0.001	0.001	0.000
Nov	81	0.000	0.000	0.000	0.000	0.000	0.440	0.050	0.000
Nov	79	0.000	0.320	0.680	0.000	0.000	0.000	0.040	0.001
Nov	78	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.170
Nov	77	0.000	0.001	0.001	0.750	0.150	0.100	0.930	0.480
Nov	72	0.030	0.300	0.200	0.000	0.001	0.000	0.000	1.290
Nov	71	0.010	0.640	0.001	0.001	0.000	0.000	0.001	0.001
Mon	Yr	One	Two	Thr	For	Fiv	Six	Sev	Eig
Dec	86	0.000	0.001	0.730	0.010	0.001	0.001	0.000	0.001
Dec	85	0.060	0.470	0.020	0.001	0.000	0.280	0.001	0.000
Dec	84	0.130	0.000	0.140	0.310	0.000	0.620	0.010	0.001
Dec	83	0.001	0.001	0.230	0.380	0.320	0.020	0.610	0.001
Dec	82	0.001	0.020	0.010	0.001	0.000	0.260	0.001	0.000
Dec	81	0.040	0.490	0.001	0.020	0.080	0.000	0.000	0.130
Dec	80	0.000	0.000	0.190	0.001	0.000	0.000	0.001	0.020
Dec	79	0.001	0.030	0.001	0.000	0.000	0.000	0.050	0.010
Dec	78	0.000	0.000	0.001	0.510	0.020	0.000	0.000	0.090
Dec	77	0.570	0.001	0.001	0.050	0.120	0.700	0.250	0.001

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Sep	86	0.000	0.000	0.000	0.110	0.010	0.000	0.000	0.120
Sep	85	0.400	1.250	0.001	0.000	0.000	0.000	0.000	0.000
Sep	83	0.000	0.000	0.000	0.020	0.230	0.040	0.000	0.000
Sep	82	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.390
Sep	81	0.260	0.000	0.000	0.000	0.050	0.000	0.380	0.190
Sep	80	0.000	0.001	0.000	0.000	0.000	0.150	0.010	0.000
Sep	79	0.000	0.000	0.000	0.000	0.000	0.080	0.160	0.000
Sep	78	0.001	0.000	0.010	0.000	0.260	0.000	0.810	0.000
Sep	77	0.000	0.000	0.000	0.000	0.001	0.470	0.000	0.300
Sep	76	0.000	0.450	0.000	0.000	0.000	0.000	0.000	0.900
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Oct	86	0.000	0.020	0.000	0.000	0.220	0.600	0.030	0.000
Oct	85	0.000	0.000	0.130	0.000	0.020	0.010	0.090	0.010
Oct	84	0.170	0.010	0.000	0.000	0.000	0.000	0.000	0.010
Oct	83	0.001	0.010	0.000	0.200	0.150	1.060	0.000	0.000
Oct	82	0.001	0.000	0.000	0.130	0.130	0.220	0.001	0.060
Oct	81	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Oct	80	0.000	0.000	0.140	0.000	0.001	0.001	0.040	0.000
Oct	79	0.040	0.060	0.040	0.070	0.150	0.001	0.001	0.000
Oct	78	0.001	0.000	0.000	0.020	0.000	0.640	0.070	0.001
Oct	77	1.120	0.150	0.000	0.010	0.000	0.000	0.620	0.620
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Nov	86	1.200	0.010	0.180	0.220	0.001	0.001	0.000	0.000
Nov	84	0.001	0.210	0.160	0.001	0.020	0.010	0.001	0.000
Nov	83	0.000	0.000	0.780	0.460	0.001	0.000	0.000	0.390
Nov	82	0.000	0.001	0.000	0.040	0.140	0.000	0.000	0.001
Nov	81	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030
Nov	79	0.001	0.200	0.010	0.001	0.020	0.010	0.020	0.080
Nov	78	0.000	0.000	0.000	0.001	0.030	0.001	0.010	0.120
Nov	77	0.040	0.001	0.870	0.010	0.050	0.001	0.000	0.000
Nov	72	0.001	0.001	0.140	0.010	0.000	0.660	0.770	0.001
Nov	71	0.001	0.010	0.001	0.000	0.000	0.000	0.240	0.001
Mon	Yr	Nin	Ten	Ele	Twe	Thi	Fort	Fift	Sixt
Dec	86	0.180	0.350	0.001	0.001	0.010	0.000	0.000	0.000
Dec	85	0.000	0.000	0.060	0.380	0.001	0.460	0.001	0.001
Dec	84	0.000	0.000	0.280	0.001	0.080	0.120	0.090	0.001
Dec	83	0.001	0.080	0.000	0.010	1.260	0.890	1.010	0.001
Dec	82	0.001	0.001	0.001	0.001	0.000	0.000	0.001	0.790
Dec	81	0.030	0.001	0.030	0.001	0.000	0.000	0.150	0.040
Dec	80	0.000	0.360	0.001	0.010	0.001	0.000	0.001	0.130
Dec	79	0.001	0.000	0.000	0.000	0.160	0.350	0.001	0.000
Dec	78	0.820	0.050	0.001	0.000	0.000	0.001	0.001	0.000
Dec	77	0.400	0.060	0.001	0.000	0.040	0.050	0.460	0.000

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Sep	86	0.000	0.000	0.550	0.010	0.160	0.000	0.001	0.850
Sep	85	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Sep	83	0.410	0.000	0.000	0.000	0.000	0.620	0.000	0.000
Sep	82	0.000	0.000	0.000	0.000	0.000	0.080	0.460	0.001
Sep	81	0.000	0.000	0.000	0.001	0.000	0.020	0.010	0.000
Sep	80	0.010	0.160	0.001	0.000	0.000	0.000	0.020	0.001
Sep	79	0.000	0.000	0.010	0.000	0.050	1.060	0.010	0.000
Sep	78	0.010	0.480	0.620	0.000	0.000	0.050	0.010	0.000
Sep	77	0.720	0.001	0.280	0.630	0.010	0.000	0.001	0.001
Sep	76	0.270	0.540	0.001	0.000	0.250	0.020	0.000	0.480
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Oct	86	0.000	0.040	0.000	0.000	0.000	0.001	0.000	0.000
Oct	85	0.000	0.000	0.000	0.001	0.001	0.110	0.010	0.020
Oct	84	0.020	0.030	0.000	0.200	0.000	0.110	0.650	0.030
Oct	83	0.000	0.000	1.300	0.000	0.000	0.000	0.260	0.120
Oct	82	0.020	0.000	0.000	0.000	0.230	0.000	0.000	0.000
Oct	81	0.000	0.210	0.050	0.130	0.000	0.000	0.160	0.080
Oct	80	0.000	0.010	0.110	0.001	0.001	0.000	0.000	0.000
Oct	79	0.010	0.030	0.000	0.000	0.000	0.000	0.000	0.660
Oct	78	0.200	0.000	0.001	0.001	0.000	0.000	0.000	0.020
Oct	77	1.450	0.001	0.020	0.540	0.000	0.000	0.001	0.001
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Nov	86	0.000	0.000	0.850	0.000	0.480	0.001	0.000	0.030
Nov	84	0.080	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Nov	83	0.030	0.001	0.010	0.000	0.650	0.000	0.000	0.080
Nov	82	0.000	0.000	0.000	0.001	0.100	0.270	0.310	0.130
Nov	81	0.001	0.001	0.001	0.280	0.020	0.001	0.001	0.001
Nov	79	0.000	0.000	0.000	0.000	0.000	0.001	0.010	0.001
Nov	78	0.050	0.280	0.000	0.000	0.001	0.010	0.000	0.290
Nov	77	0.120	0.080	0.001	0.000	0.040	0.030	0.020	0.020
Nov	72	0.000	0.000	0.000	0.540	0.001	0.001	0.020	0.001
Nov	71	0.000	0.000	0.000	0.060	0.130	0.001	0.001	0.000
Mon	Yr	Sevt	Eigt	Nint	Twty	Twone	Twtwo	Twthr	Twfor
Dec	86	0.000	0.210	0.060	0.000	0.001	0.000	0.000	0.001
Dec	85	0.070	0.030	0.001	0.000	0.020	0.001	0.060	0.001
Dec	84	0.001	0.001	0.001	0.000	0.000	0.740	0.070	0.120
Dec	83	0.001	0.001	0.001	0.000	0.000	0.740	0.070	0.120
Dec	82	0.001	0.000	0.000	0.130	0.001	0.001	0.020	0.060
Dec	81	0.010	0.150	0.001	0.010	0.001	0.070	0.190	0.001
Dec	80	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000
Dec	79	0.001	0.001	0.001	0.040	0.010	0.001	0.010	0.130
Dec	78	0.070	0.001	0.000	0.010	0.460	0.001	0.000	0.000
Dec	77	0.000	0.400	0.400	0.070	0.490	0.120	0.001	0.000

Appendix A (continued)
Precipitation Observations over a Ten Year Period
in State College, Pennsylvania

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty
Sep	86	0.060	0.360	0.210	0.001	0.000	0.000
Sep	85	0.010	0.000	0.790	0.340	0.000	0.000
Sep	83	0.000	0.001	0.000	0.000	0.000	0.000
Sep	82	0.001	0.000	1.080	0.001	0.001	0.000
Sep	81	0.000	0.000	0.000	0.001	0.000	0.000
Sep	80	0.010	0.580	0.001	0.000	0.000	0.000
Sep	79	0.000	0.000	0.000	0.070	0.960	0.010
Sep	78	0.000	0.000	0.000	0.001	0.000	0.000
Sep	77	1.130	1.180	0.001	0.001	0.010	0.001
Sep	76	0.000	0.150	0.870	0.320	0.000	0.050

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty	Thone
Oct	86	0.000	0.260	0.020	0.020	0.010	0.000	0.000
Oct	85	0.290	0.000	0.000	0.000	0.000	0.000	0.280
Oct	84	0.001	0.310	0.001	0.000	0.170	0.050	0.000
Oct	83	0.040	0.080	0.010	0.000	0.000	0.000	0.000
Oct	82	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Oct	81	0.000	0.240	1.600	1.440	0.000	0.000	0.000
Oct	80	0.570	1.230	0.001	0.070	0.001	0.000	0.000
Oct	79	0.001	0.001	0.001	0.280	0.010	0.000	0.000
Oct	78	0.000	0.020	0.360	0.000	0.000	0.000	0.000
Oct	77	0.000	0.001	0.510	0.000	0.000	0.000	0.000

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty
Nov	86	0.010	0.340	1.280	0.000	0.010	0.001
Nov	84	0.000	0.000	0.000	0.001	2.050	0.001
Nov	83	0.580	0.010	0.000	0.640	0.230	0.000
Nov	82	0.001	0.000	0.050	0.001	0.760	0.030
Nov	81	0.001	0.000	0.050	0.000	0.001	0.000
Nov	79	0.280	0.650	1.620	0.000	0.001	0.001
Nov	78	0.001	0.001	0.070	0.160	0.010	0.060
Nov	77	0.000	0.320	0.030	0.150	0.020	0.300
Nov	72	0.000	1.150	0.020	0.001	0.370	0.000
Nov	71	0.800	0.001	0.001	0.050	0.001	0.760

Mon	Yr	Twfiv	Twsix	Twsev	Tweig	Twnin	Thty	Thone
Dec	86	0.830	0.010	0.001	0.000	0.000	0.000	0.030
Dec	85	0.040	0.001	0.030	0.010	0.001	0.001	0.000
Dec	84	0.001	0.000	0.000	0.010	0.560	0.001	0.000
Dec	83	0.001	0.000	0.000	0.010	0.560	0.001	0.000
Dec	82	0.020	0.020	0.000	0.120	0.020	0.001	0.001
Dec	81	0.000	0.000	0.000	0.040	0.040	0.020	0.000
Dec	80	0.240	0.000	0.000	0.000	0.030	0.030	0.000
Dec	79	1.060	0.410	0.001	0.000	0.000	0.000	0.000
Dec	78	1.310	0.010	0.001	0.000	0.000	0.000	0.070
Dec	77	0.140	0.001	0.001	0.001	0.001	0.001	0.000

Appendix B
Cumulative Frequency of Rainfall Observations over Ten Years in State College, Pennsylvania

Jan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0"	5	7	9	6	7	8	7	10	6	8	10	7	9	8	9	7	6	9	7	5	8	6	7	7	8	7	6	6	9	10	9
#>0.1"	1	3	1	1	2	1	0	2	1	1	3	1	0	4	4	1	2	2	2	3	5	0	2	4	2	3	0	0	0	2	3
#>0.2"	1	2	1	1	0	0	0	2	1	0	2	0	0	2	2	1	0	2	0	3	4	0	1	2	2	2	0	0	0	0	1
#>0.3"	1	2	1	1	0	0	0	2	1	0	1	0	0	1	1	0	0	1	0	3	4	0	1	0	1	2	0	0	0	0	0
#>0.4"	1	2	0	1	0	0	0	2	1	0	0	0	0	1	1	0	0	1	0	3	4	0	1	0	1	2	0	0	0	0	0
#>0.5"	0	2	0	1	0	0	0	2	1	0	0	0	0	1	1	0	0	1	0	3	3	0	1	0	1	1	0	0	0	0	0
#>0.6"	0	1	0	1	0	0	0	2	1	0	0	0	0	1	1	0	0	1	0	2	3	0	1	0	1	1	0	0	0	0	0
#>0.7"	0	1	0	1	0	0	0	2	1	0	0	0	0	1	0	0	0	1	0	2	2	0	1	0	1	1	0	0	0	0	0
#>0.8"	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0
#>0.9"	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0
#>1.0"	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0

Feb	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	8	8	6	7	7	7	7	7	8	5	6	8	8	6	6	6	7	7	5	4	5	7	7	7	7	5	5	6	2	0	0
#>0.1	1	4	3	2	1	1	2	2	2	0	3	3	3	2	1	3	1	2	3	3	1	3	3	2	3	1	1	1	1	0	0
#>0.2	1	3	1	1	1	0	2	2	2	0	3	2	3	2	1	2	1	1	2	3	1	2	2	2	0	1	1	0	1	0	0
#>0.3	1	3	1	1	1	0	2	0	0	0	3	0	1	2	1	0	0	1	1	3	1	2	1	1	0	1	0	0	1	0	0
#>0.4	1	3	1	1	1	0	1	0	0	0	2	0	1	1	1	0	0	1	1	1	1	0	0	1	0	1	0	0	1	0	0
#>0.5	1	3	0	0	1	0	1	0	0	0	2	0	1	1	1	0	0	1	0	1	0	0	0	1	0	1	0	0	1	0	0
#>0.6	1	2	0	0	0	0	0	0	0	0	2	0	1	1	1	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0
#>0.7	1	2	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0
#>0.8	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0
#>0.9	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
#>1.0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0

Mar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	5	6	6	7	9	6	6	5	7	6	7	8	7	7	7	5	5	5	5	5	7	6	7	4	5	6	6	6	7	6	6
#>0.1	1	1	3	0	3	3	2	2	3	1	3	2	3	3	4	0	2	1	1	2	4	4	1	2	2	3	1	2	3	2	4
#>0.2	1	0	1	0	2	2	2	2	2	1	1	1	2	3	3	0	2	1	1	1	3	4	1	2	2	3	1	1	3	1	3
#>0.3	1	0	0	0	1	2	1	2	2	1	0	1	0	1	2	0	1	1	1	0	2	2	1	1	2	2	1	1	3	1	3
#>0.4	1	0	0	0	1	1	0	0	1	0	0	1	0	1	2	0	1	0	1	0	1	2	1	1	2	2	0	1	3	1	2
#>0.5	0	0	0	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	2	1	1	1	2	0	1	2	1	2
#>0.6	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2	0	1	1	0	0	1	2	1	1
#>0.7	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	1	1	0	0	1	2	0	1
#>0.8	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1	2	0	1
#>0.9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1
#>1.0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1

Appendix B (continued)
Cumulative Frequency of Rainfall Observations over Ten Years in State College, Pennsylvania

Apr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	8	8	8	7	10	7	9	6	6	6	7	8	7	7	5	6	6	5	3	6	7	3	3	7	8	4	7	4	5	5	0
#>0.1	4	2	3	4	4	5	5	2	3	4	0	2	3	3	3	2	2	2	1	2	1	1	1	4	3	1	2	3	2	1	0
#>0.2	3	1	3	4	4	3	4	1	3	4	0	1	2	2	3	2	1	1	1	1	0	1	0	3	2	1	2	1	2	1	0
#>0.3	2	1	3	2	4	2	1	1	2	3	0	1	1	2	2	1	1	1	0	1	0	1	0	3	1	1	2	0	2	1	0
#>0.4	2	1	2	2	4	2	1	0	2	2	0	1	0	1	2	1	1	0	0	1	0	0	0	3	1	0	2	0	2	1	0
#>0.5	1	0	2	2	1	0	1	0	1	1	0	1	0	1	2	1	1	0	0	1	0	0	0	1	1	0	0	0	2	1	0
#>0.6	1	0	2	2	0	0	0	0	1	1	0	1	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0
#>0.7	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0
#>0.8	0	0	1	1	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0
#>0.9	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
#>1.0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	4	6	6	7	7	4	5	6	5	4	4	5	8	5	5	6	3	5	6	7	6	5	4	6	5	5	5	4	6	7	7
#>0.1	1	2	4	4	3	0	1	1	4	0	3	3	1	2	1	5	2	3	3	2	3	1	3	4	4	2	0	2	4	1	3
#>0.2	1	2	1	3	1	0	1	1	2	0	1	3	1	2	1	2	2	2	3	2	2	1	3	3	2	1	0	1	4	1	2
#>0.3	1	1	1	2	1	0	0	1	2	0	1	2	1	1	1	2	2	0	2	2	1	1	2	2	1	1	0	1	3	0	2
#>0.4	1	1	0	2	1	0	0	1	1	0	0	2	1	1	1	1	2	0	2	2	0	0	2	2	1	1	0	1	3	0	1
#>0.5	1	0	0	2	1	0	0	1	0	0	0	2	1	1	1	0	2	0	1	2	0	0	2	2	1	1	0	1	2	0	1
#>0.6	1	0	0	1	0	0	0	1	0	0	0	1	1	1	1	0	1	0	1	1	0	0	2	2	1	1	0	0	2	0	0
#>0.7	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	0	0	2	2	1	1	0	0	1	0	0
#>0.8	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	[illegible]	0	2	2	0	1	0	0	1	0	0
#>0.9	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	2	2	0	1	0	0	1	0	0
#>1.0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	2	0	1	0	0	1	0	0

Jun	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	7	7	5	7	5	6	8	6	6	7	6	3	5	6	5	3	8	7	5	6	6	4	5	2	2	4	2	5	7	7	0
#>0.1	3	3	2	4	2	2	4	3	4	3	3	2	3	3	2	1	5	4	1	3	2	2	3	0	1	2	1	3	4	3	0
#>0.2	1	2	2	3	2	2	3	3	4	2	2	2	2	3	2	1	3	3	1	1	2	2	2	0	1	2	0	3	3	1	0
#>0.3	1	1	2	3	2	2	2	2	3	2	2	1	1	2	2	1	3	2	1	0	1	2	0	0	1	2	0	1	2	1	0
#>0.4	0	0	1	3	2	2	1	2	2	1	1	1	1	2	2	0	3	2	1	0	1	2	0	0	1	2	0	1	2	1	0
#>0.5	0	0	1	3	2	2	1	1	2	1	1	1	1	1	1	0	1	1	1	0	1	1	0	0	1	2	0	1	2	1	0
#>0.6	0	0	0	2	1	1	1	1	2	0	1	1	1	1	1	0	1	1	1	0	1	1	0	0	0	1	0	1	2	1	0
#>0.7	0	0	0	1	0	1	1	0	1	0	1	1	0	0	1	0	0	1	0	0	1	1	0	0	0	1	0	0	1	1	0
#>0.8	0	0	0	1	0	1	1	0	1	0	1	1	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0
#>0.9	0	0	0	1	0	1	1	0	1	0	1	1	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0
#>1.0	0	0	0	1	0	1	1	0	1	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0

Appendix B (continued)
Cumulative Frequency of Rainfall Observations over Ten Years in State College, Pennsylvania

Jul	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	7	5	8	7	7	5	3	3	4	5	6	6	4	3	3	4	6	4	3	6	4	5	2	3	4	6	6	3	5	4	5
#>0.1	2	4	2	3	4	1	3	2	2	2	2	4	2	0	2	1	3	3	1	4	2	3	1	3	1	3	3	2	3	2	3
#>0.2	2	4	2	2	1	1	2	2	2	1	1	2	2	0	2	0	2	3	0	4	1	1	0	2	1	2	3	2	3	1	3
#>0.3	1	4	2	1	0	1	2	2	2	0	1	2	1	0	1	0	2	3	0	4	1	0	0	2	1	1	3	2	3	1	1
#>0.4	1	4	1	1	0	0	1	2	1	0	0	1	0	0	0	0	2	1	0	4	1	0	0	2	1	1	2	2	2	1	1
#>0.5	1	3	1	1	0	0	0	2	0	0	0	1	0	0	0	0	2	0	0	2	1	0	0	1	0	1	2	1	1	1	1
#>0.6	1	3	1	1	0	0	0	1	0	0	0	1	0	0	0	0	2	0	0	2	1	0	0	1	0	1	1	1	1	0	0
#>0.7	1	3	1	1	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	2	1	0	0	1	0	1	1	1	0	0	0
#>0.8	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	1	0	1	1	1	0	0	0
#>0.9	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	1	0	1	0	1	0	0	0
#>1.0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	0	0	0	0

Aug	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	5	3	4	5	3	4	7	9	7	4	7	9	5	4	4	4	5	4	3	3	4	5	1	4	5	2	5	4	5	5	7
#>0.1	0	1	3	3	1	1	3	5	3	3	3	4	2	1	3	0	2	2	3	1	1	1	0	1	3	1	1	1	1	1	5
#>0.2	0	1	2	3	1	1	1	4	1	2	3	4	1	0	3	0	1	2	2	0	0	0	0	1	2	1	1	0	0	1	3
#>0.3	0	1	1	3	1	0	1	4	0	2	2	4	1	0	1	0	1	1	2	0	0	0	0	1	2	0	1	0	0	1	3
#>0.4	0	0	1	2	1	0	1	4	0	2	1	4	0	0	1	0	1	1	1	0	0	0	0	1	2	0	1	0	0	1	2
#>0.5	0	0	1	2	1	0	1	3	0	2	1	4	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0
#>0.6	0	0	1	2	1	0	1	2	0	2	1	4	0	0	0	0	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0
#>0.7	0	0	0	1	1	0	0	1	0	2	1	3	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0
#>0.8	0	0	0	1	0	0	0	0	0	1	1	3	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0
#>0.9	0	0	0	1	0	0	0	0	0	1	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
#>1.0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Sep	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	4	4	6	3	5	5	4	5	3	3	2	2	5	4	4	5	5	4	6	3	4	6	8	5	5	5	6	8	3	3	0
#>0.1	1	2	4	2	1	2	0	0	2	2	0	1	2	2	3	5	3	3	3	1	2	2	1	2	1	4	4	2	1	0	0
#>0.2	1	1	3	1	1	1	0	0	2	2	0	0	2	1	2	3	3	2	3	1	1	2	1	2	1	3	4	2	1	0	0
#>0.3	1	1	2	1	0	1	0	0	1	2	0	0	0	1	2	2	2	2	2	1	0	2	1	2	1	3	3	2	1	0	0
#>0.4	0	1	2	1	0	1	0	0	0	2	0	0	0	1	1	1	2	2	2	1	0	2	1	2	1	2	3	0	1	0	0
#>0.5	0	1	2	1	0	1	0	0	0	1	0	0	0	0	1	1	1	1	2	1	0	2	0	1	1	2	3	0	1	0	0
#>0.6	0	0	2	0	0	1	0	0	0	1	0	0	0	0	1	1	1	0	1	1	0	2	0	1	1	1	3	0	1	0	0
#>0.7	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	1	0	1	1	1	3	0	1	0	0
#>0.8	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	1	1	1	2	0	1	0	0
#>0.9	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	1	0	0
#>1.0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	0

Appendix B (continued)

Cumulative Frequency of Rainfall Observations over Ten Years in State College, Pennsylvania

Oct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	6	8	6	6	7	8	6	6	6	5	3	5	6	7	7	6	5	6	5	6	3	3	5	7	5	8	8	4	4	1	2
#>0.1	4	4	1	4	1	3	1	0	2	1	2	2	4	4	1	1	2	1	2	3	1	2	3	2	2	4	3	2	1	0	1
#>0.2	3	2	1	4	0	1	0	0	1	0	0	0	1	4	1	1	1	1	1	1	1	0	2	1	2	4	3	2	0	0	1
#>0.3	3	2	1	4	0	1	0	0	1	0	0	0	0	3	1	1	1	0	1	1	0	0	1	1	1	2	3	1	0	0	0
#>0.4	3	2	1	3	0	1	0	0	1	0	0	0	0	3	1	1	1	0	1	1	0	0	1	1	1	1	2	1	0	0	0
#>0.5	2	2	1	3	0	1	0	0	1	0	0	0	0	3	1	1	1	0	1	1	0	0	1	1	1	1	2	1	0	0	0
#>0.6	2	0	1	2	0	1	0	0	1	0	0	0	0	2	1	1	1	0	1	0	0	0	1	1	0	1	1	1	0	0	0
#>0.7	0	0	1	2	0	1	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0	0
#>0.8	0	0	1	1	0	1	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0	0
#>0.9	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0	0
#>1.0	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0	0

Nov	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	3	5	5	5	6	6	7	7	6	7	7	8	7	6	5	7	5	5	5	4	8	8	6	8	7	7	8	7	10	7	0
#>0.1	0	3	3	2	3	2	1	4	1	2	5	2	1	1	2	2	1	1	1	2	3	1	1	2	3	4	2	3	4	2	0
#>0.2	0	3	1	2	2	2	1	3	1	1	2	2	0	1	2	1	0	1	1	2	2	1	1	1	3	4	2	1	4	2	0
#>0.3	0	2	1	1	2	2	1	3	1	0	2	1	0	1	1	1	0	0	1	1	2	0	1	0	2	4	2	1	3	1	0
#>0.4	0	1	1	1	2	2	1	3	1	0	2	1	0	1	1	0	0	0	1	1	2	0	0	0	2	2	2	1	2	1	0
#>0.5	0	1	1	1	2	0	1	1	1	0	2	0	0	1	1	0	0	0	1	1	1	0	0	0	2	2	2	1	2	1	0
#>0.6	0	1	1	1	2	0	1	1	1	0	2	0	0	1	1	0	0	0	1	0	1	0	0	0	1	2	2	1	2	1	0
#>0.7	0	0	0	1	1	0	1	1	1	0	2	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1	2	0	2	1	0
#>0.8	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2	0	1	0	0
#>0.9	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	0
#>1.0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	1	0	0

Dec	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
#>0.0	7	7	10	9	5	6	7	8	7	7	8	7	7	6	9	6	8	8	8	6	7	8	7	7	9	6	5	6	7	7	3
#>0.1	2	2	4	3	2	4	2	1	3	2	1	1	2	4	3	2	0	3	1	1	2	3	1	3	5	1	0	1	2	0	0
#>0.2	1	2	2	3	1	4	2	0	2	2	1	1	1	3	2	1	0	2	1	0	2	2	0	0	4	1	0	0	2	0	0
#>0.3	1	2	1	3	1	2	1	0	2	2	0	1	1	3	2	1	0	1	1	0	2	2	0	0	3	1	0	0	2	0	0
#>0.4	1	2	1	1	0	2	1	0	1	0	0	0	1	2	2	1	0	0	0	0	2	2	0	0	3	1	0	0	2	0	0
#>0.5	1	0	1	1	0	2	1	0	1	0	0	0	1	1	1	1	0	0	0	0	0	2	0	0	3	0	0	0	2	0	0
#>0.6	0	0	1	0	0	2	1	0	1	0	0	0	1	1	1	1	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0
#>0.7	0	0	1	0	0	0	0	0	1	0	0	0	1	1	1	1	0	0	0	0	0	2	0	0	3	0	0	0	0	0	0
#>0.8	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
#>0.9	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
#>1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0

Appendix C
Survey Form Used For Local Survey

Survey Form

1. Contractor Name/Address: ____________________

2. Phone number/Name of respondant: ____________________

3. Project Type/Location: ____________________

4. Project Cost:$ ____________________

5. What kind of schedule are you using or are required to use on the project?

   a. bar chart
   b. CPM/PERT
   c. linear schedule
   d. other: ____________________

6. Does your organization schedule weather into your construction schedules? YES / NO

7. If you answered 'YES' to question 6 above, how do you include weather?

   a. use less-than 5-day work weeks
   b. add contingency time at the end of the job for weather
   c. increase the planned durations of activities expected to be affected by weather
   d. not sure
   e. other: ____________________

8. Does your contract allow time extensions for "unusual weather" (or contain similar language)? YES / NO / NOT SURE

9. Have you ever had a project dispute regarding a time extension for weather delays? YES / NO

10. Do you maintain 'lost work day' records? YES / NO

11. If you answere 'YES' to question 10 above, what kind of records do you maintain?

a. marked-up calendar
b. job diary
c. personal diary
d. foremen reports/daily job reports
e. other: ______________________________

12. How much rain does it take before you decide to stop work?

a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______________________________

13. Would you be willing to participate in a short follow-up interview/discussion (depending on total survey results)? YES / NO

14. Please indicate on the following calendars lost time due to weather for the months of October, November and December 1986. An example of the information needed is provided below:

EXAMPLE

X = whole day lost
0 = partial day lost

OCTOBER 1986

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	~~3~~	4
5	6	7	8	9	10	11
12	~~13~~	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

OCTOBER 1986

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

NOVEMBER 1986

SUN	MON	TUE	WED	THU	FRI	SAT
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

DECEMBER 1986

SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	30			

Thank you for your participation in this survey. Your efforts are greatly appreciated.

Appendix D
Survey Form Used For Non-Local Survey

Survey Form

YOU MAY CIRCLE MORE THAN ONE RESPONSE TO MULTIPLE CHOICE QUESTIONS, IF APPROPRIATE

1. Name/Address of Organization: ______________________________
____
____
____
____

2. phone number/name of respondant: ___________________________
____

3. Type of Organization:

   a. Contractor
   b. Construction Management
   c. Scheduling Consultant
   d. Other: ____
   ____

4. Does your organization schedule weather into your construction schedules? YES / NO

5. If you answered 'YES' to question 4 above, how do you include weather?

   a. use less-than 5-day work weeks
   b. add contingency time at the end of the job for weather
   c. increase the planned durations of activities expected to be affected by weather
   d. not sure
   e. other: ____
   ____
   ____

6. If you answered 'NO' to question 4 above, why don't you consider weather?

a. Excusable delays due to errors and omissions in contract documents more than compensate for failing to consider normal weather delays.
b. Jobs are bid all over the State/region/country. Considering weather while preparing bids would complicate matters and possibly cause late bids.
c. Weather delays aren't included because scheduling handbooks and other references contain no definitive guidance on how to do so.
d. Cost-plus construction contracts with no set completion dates are our main source of business.
e. Fast-Track construction contracts are our main source of business. It is extremely difficult to try to factor weather into schedules and not worth the effort.
f. other:________________

7. Do construction contracts that you are involved with allow time extensions for "unusual weather" (or contain similar language)? YES / NO / NOT SURE

8. Have you ever had a project dispute regarding a time extension for weather delays? YES / NO

9. If you answered 'YES' to question 8 above, did you validate your position in the dispute by:

a. identifying work impacted by weather as being on the critical path.
b. establishing that the controlling work was delayed by the weather.
c. establishing that the weather was unforeseeable (meaning 'abnormally severe').
d. other:________________

10. Do you maintain 'lost work day' records? YES / NO

11. If you answere 'YES' to question 10 above, what kind of records do you maintain?

a. marked-up calendar
b. job diary
c. personal diary
d. foremen reports/daily job reports
e. other:________________

12. How much rain does it take before you decide to stop the following work?

<u>clearing and grubbing</u>
a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______________________

<u>excavation/earthwork</u>
a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______________________

<u>foundations - concrete</u>
a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______________________

<u>concrete slabs</u>
a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______________________

<u>structural steelwork</u>
a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______________________

<u>exterior masonry</u>

a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______

<u>roofing</u>

a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______

<u>exterior painting</u>

a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______

<u>wooden framing</u>

a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______

<u>asphalt paving</u>

a. up to 1/8"
b. 1/8" to 1/4"
c. 1/4" to 1/2"
d. over 1/2"
e. other: ______

13. Would you be willing to participate in a short follow-up interview/discussion (depending on total survey results)?
YES / NO

14. Comments?: ______

Thank you for your participation in this survey!

Appendix E
Organized Rain Data for Weather Scheduling Model
(Cumulative Frequency of Rainfall Observations for State College, Pennsylvania for the Ten Year Period, 1977-1986)

Ref: page 60.

Sep	21	22	23	24	25	28	29	30
#>0.10	2	2	1	2	1	2	1	0
#>0.15	2	2	1	2	1	2	1	0
#>0.30	0	2	1	2	1	2	1	0

Oct	1	2	5	6	7	8	9	13	14	15	16	19	20	21	22	23	26	27	28	29	30
#>0.10	4	4	1	3	1	0	2	4	4	1	1	2	3	1	2	3	4	3	2	1	0
#>0.15	3	3	0	3	1	0	2	1	4	1	1	1	2	1	0	3	4	3	2	1	0
#>0.30	3	2	0	1	0	0	1	0	3	1	1	1	1	0	0	1	2	3	1	0	0

Nov	2	3	4	5	6	9	10	12	13	16	17	18	19	20	23	24	25	27	30
#>0.10	3	3	2	3	2	1	2	2	1	2	1	1	1	2	1	2	3	2	2
#>0.15	3	3	2	2	2	1	2	2	0	1	0	1	1	2	1	1	3	2	2
#>0.30	2	1	1	2	2	1	0	1	0	1	0	0	1	1	1	0	2	2	1

Dec	1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	28	29	30	31
#>0.10	2	2	4	3	2	1	3	2	1	4	3	2	0	3	2	3	1	3	1	2	0	0
#>0.15	1	2	3	3	2	0	3	2	1	3	2	1	0	2	2	2	1	0	0	2	0	0
#>0.30	1	2	1	3	1	0	2	2	0	3	2	1	0	1	2	2	0	0	0	2	0	0

Jan	4	5	6	7	8	11	12	13	14	18	19	20	21	22	25	26	27	28	29
#>0.10	1	2	1	0	2	3	1	0	4	2	2	3	5	0	2	3	0	0	0
#>0.15	1	1	0	0	2	3	0	0	3	2	1	3	4	0	2	2	0	0	0
#>0.30	1	0	0	0	2	1	0	0	1	1	0	3	4	0	1	2	0	0	0

Feb	1	2	3	4	5	8	9	10	11	12	15	16	17	18	19	23	24	25	26	29
#>0.10	1	4	3	2	1	2	2	0	3	3	1	3	1	2	3	3	2	3	1	1
#>0.15	1	3	2	1	1	2	2	0	3	2	1	2	1	2	2	2	2	1	1	1
#>0.30	1	3	1	1	1	0	0	0	3	0	1	0	0	1	1	1	1	0	1	1

Mar	1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	25	28	29	30	31
#>0.10	1	1	3	0	2	2	3	1	3	3	4	0	2	1	4	4	1	2	2	2	3	2	4
#>0.15	1	0	1	0	2	2	2	1	2	3	3	0	2	1	4	4	1	2	2	1	3	2	4
#>0.30	1	0	0	0	1	2	2	1	0	1	2	0	1	1	2	2	1	1	2	1	3	1	3

Apr	1	4	5	6	7	8	11	12	13	14	18	19	20	21	22	25	26	27	28	29
#>0.10	4	4	4	5	5	2	0	2	3	3	2	1	2	1	1	3	1	2	3	2
#>0.15	3	4	4	4	4	1	0	1	3	3	1	1	2	1	1	2	1	2	2	2
#>0.30	2	2	4	2	1	1	0	1	1	2	1	0	1	0	1	1	1	2	0	2

END

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